

Title: Inbred Maize Line PH51H

Anticipated Class: 800

Subclass: 200

Art Unit: 1649

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**Field of the Invention**

This invention is in the field of maize breeding, specifically relating to an inbred maize line designated PH51H.

**Background of the Invention**

The goal of plant breeding is to combine in a single variety or hybrid various desirable traits. For field crops, these traits may include resistance to diseases and insects, tolerance to heat and drought, reducing the time to crop maturity, greater yield, and better agronomic quality. With mechanical harvesting of many crops, uniformity of plant characteristics such as germination and stand establishment, growth rate, maturity, and plant and ear height, is important.

Field crops are bred through techniques that take advantage of the plant's method of pollination. A plant is self-pollinated if pollen from one flower is transferred to the same or another flower of the same plant. A plant is cross-pollinated if the pollen comes from a flower on a different plant.

Plants that have been self-pollinated and selected for type for many generations become homozygous at almost all gene loci and produce a uniform population of true breeding progeny. A cross between two different homozygous lines produces a uniform population of hybrid plants that may be heterozygous for many gene loci. A cross of two plants each heterozygous at a number of gene loci will produce a population of hybrid plants that differ genetically and will not be uniform.

Maize (*zea mays* L.), often referred to as corn in the United States, can be bred by both self-pollination and cross-pollination techniques. Maize has separate male and female flowers on the same plant, located on the tassel and the ear, respectively. Natural pollination occurs in maize when wind blows pollen from the tassels to the silks that protrude from the tops of the ears.

A reliable method of controlling male fertility in plants offers the opportunity for improved plant breeding. This is especially true for development of maize hybrids,

which relies upon some sort of male sterility system. There are several options for controlling male fertility available to breeders, such as: manual or mechanical emasculation (or detasseling), cytoplasmic male sterility, genetic male sterility, gametocides and the like.

5           Hybrid maize seed is typically produced by a male sterility system incorporating manual or mechanical detasseling. Alternate strips of two maize inbreds are planted in a field, and the pollen-bearing tassels are removed from one of the inbreds (female). Providing that there is sufficient isolation from sources of foreign maize pollen, the ears of the detasseled inbred will be fertilized only from the other inbred (male), and the  
10       resulting seed is therefore hybrid and will form hybrid plants.

          The laborious, and occasionally unreliable, detasseling process can be avoided by using cytoplasmic male-sterile (CMS) inbreds. Plants of a CMS inbred are male sterile as a result of factors resulting from the cytoplasmic, as opposed to the nuclear, genome. Thus, this characteristic is inherited exclusively through the female parent in  
15       maize plants, since only the female provides cytoplasm to the fertilized seed. CMS plants are fertilized with pollen from another inbred that is not male-sterile. Pollen from the second inbred may or may not contribute genes that make the hybrid plants male-fertile. Seed from detasseled fertile maize and CMS produced seed of the same hybrid can be blended to insure that adequate pollen loads are available for fertilization when  
20       the hybrid plants are grown.

          There are several methods of conferring genetic male sterility available, such as multiple mutant genes at separate locations within the genome that confer male sterility, as disclosed in U.S. Patents 4,654,465 and 4,727,219 to Brar et al. and chromosomal translocations as described by Patterson in U.S. Patents No. 3,861,709 and 3,710,511.  
25       These and all patents referred to are incorporated by reference. In addition to these methods, Albertsen et al., of Pioneer Hi-Bred, U.S. Patent No. 5,432,068, have developed a system of nuclear male sterility which includes: identifying a gene which is critical to male fertility; silencing this native gene which is critical to male fertility; removing the native promoter from the essential male fertility gene and replacing it with  
30       an inducible promoter; inserting this genetically engineered gene back into the plant; and thus creating a plant that is male sterile because the inducible promoter is not "on" resulting in the male fertility gene not being transcribed. Fertility is restored by inducing, or turning "on", the promoter, which in turn allows the gene that confers male fertility to be transcribed.

There are many other methods of conferring genetic male sterility in the art, each with its own benefits and drawbacks. These methods use a variety of approaches such as delivering into the plant a gene encoding a cytotoxic substance associated with a male tissue specific promoter or an antisense system in which a gene critical to fertility is identified and an antisense to that gene is inserted in the plant (see: Fabinjanski, et al. EPO 89/3010153.8 publication no. 329,308 and PCT application PCT/CA90/00037 published as WO 90/08828).

Another system useful in controlling male sterility makes use of gametocides. Gametocides are not a genetic system, but rather a topical application of chemicals. These chemicals affect cells that are critical to male fertility. The application of these chemicals affects fertility in the plants only for the growing season in which the gametocide is applied (see Carlson, Glenn R., U.S. Patent Number: 4,936,904). Application of the gametocide, timing of the application and genotype specificity often limit the usefulness of the approach.

#### **Development of Maize Inbred Lines**

The use of male sterile inbreds is but one factor in the production of maize hybrids. Plant breeding techniques known in the art and used in a maize plant breeding program include, but are not limited to, recurrent selection, backcrossing, pedigree breeding, restriction length polymorphism enhanced selection, genetic marker enhanced selection and transformation. The development of maize hybrids in a maize plant breeding program requires, in general, the development of homozygous inbred lines, the crossing of these lines, and the evaluation of the crosses. Pedigree breeding and recurrent selection breeding methods are used to develop inbred lines from breeding populations. Maize plant breeding programs combine the genetic backgrounds from two or more inbred lines or various other germplasm sources into breeding pools from which new inbred lines are developed by selfing and selection of desired phenotypes. The new inbreds are crossed with other inbred lines and the hybrids from these crosses are evaluated to determine which of those have commercial potential. Plant breeding and hybrid development, as practiced in a maize plant breeding program, are expensive and time consuming processes.

Pedigree breeding starts with the crossing of two genotypes, each of which may have one or more desirable characteristics that is lacking in the other or which complements the other. If the two original parents do not provide all the desired characteristics, other sources can be included in the breeding population. In the

pedigree method, superior plants are selfed and selected in successive generations. In the succeeding generations the heterozygous condition gives way to homogeneous lines as a result of self-pollination and selection. Typically in the pedigree method of breeding five or more generations of selfing and selection is practiced:  $F_1 \rightarrow F_2$ ;  $F_2 \rightarrow F_3$ .

5  $F_3 \rightarrow F_4$ ;  $F_4 \rightarrow F_5$ , etc.

Recurrent selection breeding, backcrossing for example, can be used to improve an inbred line and a hybrid which is made using those inbreds. Backcrossing can be used to transfer a specific desirable trait from one inbred or source to an inbred that lacks that trait. This can be accomplished, for example, by first crossing a superior  
10 inbred (recurrent parent) to a donor inbred (non-recurrent parent), that carries the appropriate gene(s) for the trait in question. The progeny of this cross is then mated back to the superior recurrent parent followed by selection in the resultant progeny for the desired trait to be transferred from the non-recurrent parent. After five or more  
15 backcross generations with selection for the desired trait, the progeny will be homozygous for loci controlling the characteristic being transferred, but will be like the superior parent for essentially all other genes. The last backcross generation is then selfed to give pure breeding progeny for the gene(s) being transferred. A hybrid developed from inbreds containing the transferred gene(s) is essentially the same as a hybrid developed from the same inbreds without the transferred gene(s).

20 Elite inbred lines, that is, pure breeding, homozygous inbred lines, can also be used as starting materials for breeding or source populations from which to develop other inbred lines. These inbred lines derived from elite inbred lines can be developed using the pedigree breeding and recurrent selection breeding methods described earlier. As an example, when backcross breeding is used to create these derived lines in a  
25 maize plant breeding program, elite inbreds can be used as a parental line or starting material or source population and can serve as either the donor or recurrent parent.

### **Development of Maize Hybrids**

A single cross maize hybrid results from the cross of two inbred lines, each of which has a genotype that complements the genotype of the other. The hybrid progeny  
30 of the first generation is designated  $F_1$ . In the development of commercial hybrids in a maize plant breeding program, only the  $F_1$  hybrid plants are sought. Preferred  $F_1$  hybrids are more vigorous than their inbred parents. This hybrid vigor, or heterosis, can be manifested in many polygenic traits, including increased vegetative growth and increased yield.

The development of a maize hybrid in a maize plant breeding program involves three steps: (1) the selection of plants from various germplasm pools for initial breeding crosses; (2) the selfing of the selected plants from the breeding crosses for several generations to produce a series of inbred lines, which, although different from each other, breed true and are highly uniform; and (3) crossing the selected inbred lines with different inbred lines to produce the hybrid progeny ( $F_1$ ). During the inbreeding process in maize, the vigor of the lines decreases. Vigor is restored when two different inbred lines are crossed to produce the hybrid progeny ( $F_1$ ). An important consequence of the homozygosity and homogeneity of the inbred lines is that the hybrid between a defined pair of inbreds will always be the same. Once the inbreds that give a superior hybrid have been identified, the hybrid seed can be reproduced indefinitely as long as the homogeneity of the inbred parents is maintained.

A single cross hybrid is produced when two inbred lines are crossed to produce the  $F_1$  progeny. A double cross hybrid is produced from four inbred lines (or synthetics) crossed in pairs ( $A \times B$  and  $C \times D$ ) and then the two  $F_1$  hybrids are crossed again ( $A \times B$ )  $\times$  ( $C \times D$ ). A three-way cross hybrid is produced from three inbred lines (or synthetics) where two of the inbred lines (or synthetics) are crossed ( $A \times B$ ) and then the resulting  $F_1$  hybrid is crossed with the third inbred (or synthetics) ( $A \times B$ )  $\times$   $C$ . Much of the hybrid vigor exhibited by  $F_1$  hybrids is lost in the next generation ( $F_2$ ). Consequently, seed from hybrids is not used for planting stock.

Hybrid seed production requires elimination or inactivation of pollen produced by the female parent. Incomplete removal or inactivation of the pollen provides the potential for self pollination. This inadvertently self pollinated seed may be unintentionally harvested and packaged with hybrid seed.

Once the seed is planted, it is possible to identify and select these self pollinated plants. These self pollinated plants will be genetically equivalent to the female inbred line used to produce the hybrid.

Typically these self pollinated plants can be identified and selected due to their decreased vigor. Female selfs are identified by their less vigorous appearance for vegetative and/or reproductive characteristics, including shorter plant height, small ear size, ear and kernel shape, cob color, or other characteristics.

Identification of these self-pollinated lines can also be accomplished through molecular marker analyses. See, "The Identification of Female Selfs in Hybrid Maize: A Comparison Using Electrophoresis and Morphology", Smith, J.S.C. and Wych, R.D.,

Seed Science and Technology 14, pp. 1-8 (1995), the disclosure of which is expressly incorporated herein by reference. Through these technologies, the homozygosity of the self pollinated line can be verified by analyzing allelic composition at various loci along the genome. Those methods allow for rapid identification of the invention disclosed  
5 herein. See also, "Identification of Atypical Plants in Hybrid Maize Seed by Postcontrol and Electrophoresis" Sarca, V. et al., Probleme de Genetica Teoritica si Aplicata Vol. 20 (1) p. 29-42.

As is readily apparent to one skilled in the art, the foregoing are only some of the various ways by which the inbred can be obtained by those looking to use the  
10 germplasm. Other means are available, and the above examples are illustrative only.

Maize is an important and valuable field crop. Thus, a continuing goal of plant breeders is to develop high-yielding maize hybrids that are agronomically sound based on stable inbred lines. The reasons for this goal are obvious: to maximize the amount of grain produced with the inputs used and minimize susceptibility of the crop to pests  
15 and environmental stresses. To accomplish this goal, the maize breeder must select and develop superior inbred parental lines for producing hybrids. This requires identification and selection of genetically unique individuals that occur in a segregating population. The segregating population is the result of a combination of crossover events plus the independent assortment of specific combinations of alleles at many  
20 gene loci that results in specific genotypes. The probability of selecting any one individual with a specific genotype from a breeding cross is infinitesimal due to the large number of segregating genes and the unlimited recombinations of these genes, some of which may be closely linked. However, the genetic variation among individual progeny of a breeding cross allows for the identification of rare and valuable new genotypes.  
25 These new genotypes are neither predictable nor incremental in value, but rather the result of manifested genetic variation combined with selection methods, environments and the actions of the breeder.

Thus, even if the entire genotypes of the parents of the breeding cross were characterized and a desired genotype known, only a few if any individuals having the  
30 desired genotype may be found in a large segregating  $F_2$  population. Typically, however, neither the genotypes of the breeding cross parents nor the desired genotype to be selected is known in any detail. In addition to the preceding problem, it is not known how the genotype would react with the environment. This genotype by environment interaction is an important, yet unpredictable, factor in plant breeding. A

breeder of ordinary skill in the art cannot predict the genotype, how that genotype will interact with various climatic conditions or the resulting phenotypes of the developing lines, except perhaps in a very broad and general fashion. A breeder of ordinary skill in the art would also be unable to recreate the same line twice from the very same original  
5 parents as the breeder is unable to direct how the genomes combine or how they will interact with the environmental conditions. This unpredictability results in the expenditure of large amounts of research resources in the development of a superior new maize inbred line.

### 10 **Summary of the Invention**

According to the invention, there is provided a novel inbred maize line, designated PH51H. This invention thus relates to the seeds of inbred maize line PH51H, to the plants of inbred maize line PH51H, to methods for producing a maize  
15 plant produced by crossing the inbred maize line PH51H with itself or another maize line, and to methods for producing a maize plant containing in its genetic material one or more transgenes and to the transgenic maize plants produced by that method. This invention also relates to inbred maize lines derived from inbred maize line PH51H, to methods for producing other inbred maize lines derived from inbred maize line PH51H and to the inbred maize lines derived by the use of those methods. This invention  
20 further relates to hybrid maize seeds and plants produced by crossing the inbred line PH51H with another maize line.

### **Definitions**

In the description and examples that follow, a number of terms are used herein.  
25 In order to provide a clear and consistent understanding of the specification and claims, including the scope to be given such terms, the following definitions are provided. NOTE: ABS is in absolute terms and %MN is percent of the mean for the experiments in which the inbred or hybrid was grown. These designators will follow the descriptors to denote how the values are to be interpreted. Below are the descriptors used in the data  
30 tables included herein.

ANT ROT = ANTHRACNOSE STALK ROT (*Colletotrichum graminicola*). A 1 to 9 visual rating indicating the resistance to Anthracnose Stalk Rot. A higher score indicates a higher resistance.

BAR PLT = BARREN PLANTS. The percent of plants per plot that were not barren (lack ears).

BRT STK = BRITTLE STALKS. This is a measure of the stalk breakage near the time of pollination, and is an indication of whether a hybrid or inbred would snap or break near the time of flowering under severe winds. Data are presented as percentage of plants that did not snap.

BU ACR = YIELD (BUSHEL/ACRE). Yield of the grain at harvest in bushels per acre adjusted to 15.5% moisture.

CLD TST = COLD TEST. The percent of plants that germinate under cold test conditions.

CLN = CORN LETHAL NECROSIS. Synergistic interaction of maize chlorotic mottle virus (MCMV) in combination with either maize dwarf mosaic virus (MDMV-A or MDMV-B) or wheat streak mosaic virus (WSMV). A 1 to 9 visual rating indicating the resistance to Corn Lethal Necrosis. A higher score indicates a higher resistance.

COM RST = COMMON RUST (*Puccinia sorghi*). A 1 to 9 visual rating indicating the resistance to Common Rust. A higher score indicates a higher resistance.

D/D = DRYDOWN. This represents the relative rate at which a hybrid will reach acceptable harvest moisture compared to other hybrids on a 1-9 rating scale. A high score indicates a hybrid that dries relatively fast while a low score indicates a hybrid that dries slowly.

DIP ERS = DIPLODIA EAR MOLD SCORES (*Diplodia maydis* and *Diplodia macrospora*). A 1 to 9 visual rating indicating the resistance to Diplodia Ear Mold. A higher score indicates a higher resistance.

DRP EAR = DROPPED EARS. A measure of the number of dropped ears per plot and represents the percentage of plants that did not drop ears prior to harvest.

D/T = DROUGHT TOLERANCE. This represents a 1-9 rating for drought tolerance, and is based on data obtained under stress conditions. A high score indicates good drought tolerance and a low score indicates poor drought tolerance.

EAR HT = EAR HEIGHT. The ear height is a measure from the ground to the highest placed developed ear node attachment and is measured in inches.

EAR MLD = General Ear Mold. Visual rating (1-9 score) where a "1" is very susceptible and a "9" is very resistant. This is based on overall rating for ear mold of mature ears without determining the specific mold organism, and may not be predictive for a specific ear mold.



EAR SZ = EAR SIZE. A 1 to 9 visual rating of ear size. The higher the rating the larger the ear size.

ECB 1LF = EUROPEAN CORN BORER FIRST GENERATION LEAF FEEDING (*Ostrinia nubilalis*). A 1 to 9 visual rating indicating the resistance to preflowering leaf feeding by first generation European Corn Borer. A higher score indicates a higher resistance.

ECB 2IT = EUROPEAN CORN BORER SECOND GENERATION INCHES OF TUNNELING (*Ostrinia nubilalis*). Average inches of tunneling per plant in the stalk.

ECB 2SC = EUROPEAN CORN BORER SECOND GENERATION (*Ostrinia nubilalis*). A 1 to 9 visual rating indicating post flowering degree of stalk breakage and other evidence of feeding by European Corn Borer, Second Generation. A higher score indicates a higher resistance.

ECB DPE = EUROPEAN CORN BORER DROPPED EARS (*Ostrinia nubilalis*). Dropped ears due to European Corn Borer. Percentage of plants that did not drop ears under second generation corn borer infestation.

EGR WTH = EARLY GROWTH. This is a measure of the relative height and size of a corn seedling at the 2-4 leaf stage of growth. This is a visual rating (1 to 9), with 1 being weak or slow growth, 5 being average growth and 9 being strong growth. Taller plants, wider leaves, more green mass and darker color constitute higher score.

EST CNT = EARLY STAND COUNT. This is a measure of the stand establishment in the spring and represents the number of plants that emerge on per plot basis for the inbred or hybrid.

EYE SPT = Eye Spot (*Kabatiella zeae* or *Aureobasidium zeae*). A 1 to 9 visual rating indicating the resistance to Eye Spot. A higher score indicates a higher resistance.

FUS ERS = FUSARIUM EAR ROT SCORE (*Fusarium moniliforme* or *Fusarium subglutinans*). A 1 to 9 visual rating indicating the resistance to Fusarium ear rot. A higher score indicates a higher resistance.

GDU = Growing Degree Units. Using the Barger Heat Unit Theory, which assumes that maize growth occurs in the temperature range 50°F - 86°F and that temperatures outside this range slow down growth; the maximum daily heat unit accumulation is 36 and the minimum daily heat unit accumulation is 0. The seasonal accumulation of GDU is a major factor in determining maturity zones.

5 GDU SHD = GDU TO SHED. The number of growing degree units (GDUs) or heat units required for an inbred line or hybrid to have approximately 50 percent of the plants shedding pollen and is measured from the time of planting. Growing degree units are calculated by the Barger Method, where the heat units for a 24-hour period are:

$$5 \quad \text{GDU} = \frac{(\text{Max. temp.} + \text{Min. temp.})}{2} - 50$$

10 The highest maximum temperature used is 86° F. and the lowest minimum temperature used is 50° F. For each inbred or hybrid it takes a certain number of GDUs to reach various stages of plant development.

GDU SLK = GDU TO SILK. The number of growing degree units required for an inbred line or hybrid to have approximately 50 percent of the plants with silk emergence from time of planting. Growing degree units are calculated by the Barger Method as given in GDU SHD definition.

15 GIB ERS = GIBBERELLA EAR ROT (PINK MOLD) (*Gibberella zeae*). A 1 to 9 visual rating indicating the resistance to Gibberella Ear Rot. A higher score indicates a higher resistance.

20 GLF SPT = Gray Leaf Spot (*Cercospora zeae-maydis*). A 1 to 9 visual rating indicating the resistance to Gray Leaf Spot. A higher score indicates a higher resistance.

GOS WLT = Goss' Wilt (*Corynebacterium nebraskense*). A 1 to 9 visual rating indicating the resistance to Goss' Wilt. A higher score indicates a higher resistance.

25 GRN APP = GRAIN APPEARANCE. This is a 1 to 9 rating for the general appearance of the shelled grain as it is harvested based on such factors as the color of harvested grain, any mold on the grain, and any cracked grain. High scores indicate good grain quality.

30 H/POP = YIELD AT HIGH DENSITY. Yield ability at relatively high plant densities on 1-9 relative rating system with a higher number indicating the hybrid responds well to high plant densities for yield relative to other hybrids. A 1, 5, and 9 would represent very poor, average, and very good yield response, respectively, to increased plant density.

HC BLT = HELMINTHOSPORIUM CARBONUM LEAF BLIGHT (*Helminthosporium carbonum*). A 1 to 9 visual rating indicating the resistance to Helminthosporium infection. A higher score indicates a higher resistance.

HD SMT = HEAD SMUT (*Sphacelotheca reiliana*). This score indicates the percentage of plants not infected.

HSK CVR = HUSK COVER. A 1 to 9 score based on performance relative to key checks, with a score of 1 indicating very short husks, tip of ear and kernels showing; 5 is intermediate coverage of the ear under most conditions, sometimes with thin husk; and a 9 has husks extending and closed beyond the tip of the ear. Scoring can best be done near physiological maturity stage or any time during dry down until harvested.

INC D/A = GROSS INCOME (DOLLARS PER ACRE). Relative income per acre assuming drying costs of two cents per point above 15.5 percent harvest moisture and current market price per bushel.

INCOME/ACRE. Income advantage of hybrid to be patented over other hybrid on per acre basis.

INC ADV = GROSS INCOME ADVANTAGE. GROSS INCOME advantage of variety #1 over variety #2.

KSZ DCD = KERNEL SIZE DISCARD. The percent of discard seed; calculated as the sum of discarded tip kernels and extra large kernels.

L/POP = YIELD AT LOW DENSITY. Yield ability at relatively low plant densities on a 1-9 relative system with a higher number indicating the hybrid responds well to low plant densities for yield relative to other hybrids. A 1, 5, and 9 would represent very poor, average, and very good yield response, respectively, to low plant density.

MDM CPX = MAIZE DWARF MOSAIC COMPLEX (MDMV = Maize Dwarf Mosaic Virus and MCDV = Maize Chlorotic Dwarf Virus). A 1 to 9 visual rating indicating the resistance to Maize Dwarf Mosaic Complex. A higher score indicates a higher resistance.

MST = HARVEST MOISTURE. The moisture is the actual percentage moisture of the grain at harvest.

MST ADV = MOISTURE ADVANTAGE. The moisture advantage of variety #1 over variety #2 as calculated by: MOISTURE of variety #2 - MOISTURE of variety #1 = MOISTURE ADVANTAGE of variety #1.

NLF BLT = Northern Leaf Blight (*Helminthosporium turcicum* or *Exserohilum turcicum*). A 1 to 9 visual rating indicating the resistance to Northern Leaf Blight. A higher score indicates a higher resistance.

OILT = GRAIN OIL. Absolute value of oil content of the kernel as predicted by Near-Infrared Transmittance and expressed as a percent of dry matter.

PLT HT = PLANT HEIGHT. This is a measure of the height of the plant from the ground to the tip of the tassel in inches.

POL SC = POLLEN SCORE. A 1 to 9 visual rating indicating the amount of pollen shed. The higher the score the more pollen shed.

5 POL WT = POLLEN WEIGHT. This is calculated by dry weight of tassels collected as shedding commences minus dry weight from similar tassels harvested after shedding is complete.

POP K/A = PLANT POPULATIONS. Measured as 1000s per acre.

10 POP ADV = PLANT POPULATION ADVANTAGE. The plant population advantage of variety #1 over variety #2 as calculated by PLANT POPULATION of variety #2 - PLANT POPULATION of variety #1 = PLANT POPULATION ADVANTAGE of variety #1.

15 PRM = PREDICTED RELATIVE MATURITY. This trait, predicted relative maturity, is based on the harvest moisture of the grain. The relative maturity rating is based on a known set of checks and utilizes standard linear regression analyses and is also referred to as the Comparative Relative Maturity Rating System that is similar to the Minnesota Relative Maturity Rating System.

20 PRM SHD = A relative measure of the growing degree units (GDU) required to reach 50% pollen shed. Relative values are predicted values from the linear regression of observed GDU's on relative maturity of commercial checks.

PROT = GRAIN PROTEIN. Absolute value of protein content of the kernel as predicted by Near-Infrared Transmittance and expressed as a percent of dry matter.

25 RT LDG = ROOT LODGING. Root lodging is the percentage of plants that do not root lodge; plants that lean from the vertical axis at an approximately 30° angle or greater would be counted as root lodged.

RTL ADV = ROOT LODGING ADVANTAGE. The root lodging advantage of variety #1 over variety #2.

30 SCT GRN = SCATTER GRAIN. A 1 to 9 visual rating indicating the amount of scatter grain (lack of pollination or kernel abortion) on the ear. The higher the score the less scatter grain.

SDG VGR = SEEDLING VIGOR. This is the visual rating (1 to 9) of the amount of vegetative growth after emergence at the seedling stage (approximately five leaves). A higher score indicates better vigor.

SEL IND = SELECTION INDEX. The selection index gives a single measure of the hybrid's worth based on information for up to five traits. A maize breeder may utilize his or her own set of traits for the selection index. One of the traits that is almost always included is yield. The selection index data presented in the tables represent the mean value averaged across testing stations.

SLF BLT = SOUTHERN LEAF BLIGHT (*Helminthosporium maydis* or *Bipolaris maydis*). A 1 to 9 visual rating indicating the resistance to Southern Leaf Blight. A higher score indicates a higher resistance.

SOU RST = SOUTHERN RUST (*Puccinia polysora*). A 1 to 9 visual rating indicating the resistance to Southern Rust. A higher score indicates a higher resistance.

STA GRN = STAY GREEN. Stay green is the measure of plant health near the time of black layer formation (physiological maturity). A high score indicates better late-season plant health.

STD ADV = STALK STANDING ADVANTAGE. The advantage of variety #1 over variety #2 for the trait STK CNT.

STK CNT = NUMBER OF PLANTS. This is the final stand or number of plants per plot.

STK LDG = STALK LODGING. This is the percentage of plants that did not stalk lodge (stalk breakage) as measured by either natural lodging or pushing the stalks and determining the percentage of plants that break below the ear.

STRT = GRAIN STARCH. Absolute value of starch content of the kernel as predicted by Near-Infrared Transmittance and expressed as a percent of dry matter.

STW WLT = Stewart's Wilt (*Erwinia stewartii*). A 1 to 9 visual rating indicating the resistance to Stewart's Wilt. A higher score indicates a higher resistance.

TAS BLS = TASSEL BLAST. A 1 to 9 visual rating was used to measure the degree of blasting (necrosis due to heat stress) of the tassel at the time of flowering. A 1 would indicate a very high level of blasting at time of flowering, while a 9 would have no tassel blasting.

TAS SZ = TASSEL SIZE. A 1 to 9 visual rating was used to indicate the relative size of the tassel. The higher the rating the larger the tassel.

TAS WT = TASSEL WEIGHT. This is the average weight of a tassel (grams) just prior to pollen shed.

TEX EAR = EAR TEXTURE. A 1 to 9 visual rating was used to indicate the relative hardness (smoothness of crown) of mature grain. A 1 would be very soft (extreme dent) while a 9 would be very hard (flinty or very smooth crown).

5 TILLER = TILLERS. A count of the number of tillers per plot that could possibly shed pollen was taken. Data are given as a percentage of tillers: number of tillers per plot divided by number of plants per plot.

TST WT = TEST WEIGHT (UNADJUSTED). The measure of the weight of the grain in pounds for a given volume (bushel).

10 TST WTA = TEST WEIGHT ADJUSTED. The measure of the weight of the grain in pounds for a given volume (bushel) adjusted for 15.5 percent moisture.

TSW ADV = TEST WEIGHT ADVANTAGE. The test weight advantage of variety #1 over variety #2.

WIN M% = PERCENT MOISTURE WINS.

WIN Y% = PERCENT YIELD WINS.

15 YLD = YIELD. It is the same as BU ACR ABS.

YLD ADV = YIELD ADVANTAGE. The yield advantage of variety #1 over variety #2 as calculated by: YIELD of variety #1 - YIELD variety #2 = yield advantage of variety #1.

20 YLD SC = YIELD SCORE. A 1 to 9 visual rating was used to give a relative rating for yield based on plot ear piles. The higher the rating the greater visual yield appearance.

### **Detailed Description of the Invention**

25 Inbred maize lines are typically developed for use in the production of hybrid maize lines. Inbred maize lines need to be highly homogeneous, homozygous and reproducible to be useful as parents of commercial hybrids. There are many analytical methods available to determine the homozygotic and phenotypic stability of these inbred lines.

30 The oldest and most traditional method of analysis is the observation of phenotypic traits. The data is usually collected in field experiments over the life of the maize plants to be examined. Phenotypic characteristics most often observed are for traits associated with plant morphology, ear and kernel morphology, insect and disease resistance, maturity, and yield.

In addition to phenotypic observations, the genotype of a plant can also be examined. There are many laboratory-based techniques available for the analysis, comparison and characterization of plant genotype; among these are Isozyme Electrophoresis, Restriction Fragment Length Polymorphisms (RFLPs), Randomly Amplified Polymorphic DNAs (RAPDs), Arbitrarily Primed Polymerase Chain Reaction (AP-PCR), DNA Amplification Fingerprinting (DAF), Sequence Characterized Amplified Regions (SCARs), Amplified Fragment Length Polymorphisms (AFLPs), and Simple Sequence Repeats (SSRs) which are also referred to as Microsatellites.

The most widely used of these laboratory techniques are Isozyme Electrophoresis and RFLPs as discussed in Lee, M., "Inbred Lines of Maize and Their Molecular Markers," *The Maize Handbook*, (Springer-Verlag, New York, Inc. 1994, at 423- 432) incorporated herein by reference. Isozyme Electrophoresis is a useful tool in determining genetic composition, although it has relatively low number of available markers and the low number of allelic variants among maize inbreds. RFLPs have the advantage of revealing an exceptionally high degree of allelic variation in maize and the number of available markers is almost limitless.

Maize RFLP linkage maps have been rapidly constructed and widely implemented in genetic studies. One such study is described in Boppenmaier, et al., "Comparisons among strains of inbreds for RFLPs", *Maize Genetics Cooperative Newsletter*, 65:1991, pg. 90, is incorporated herein by reference. This study used 101 RFLP markers to analyze the patterns of 2 to 3 different deposits each of five different inbred lines. The inbred lines had been selfed from 9 to 12 times before being adopted into 2 to 3 different breeding programs. It was results from these 2 to 3 different breeding programs that supplied the different deposits for analysis. These five lines were maintained in the separate breeding programs by selfing or sibbing and rogueing off-type plants for an additional one to eight generations. After the RFLP analysis was completed, it was determined the five lines showed 0-2% residual heterozygosity. Although this was a relatively small study, it can be seen using RFLPs that the lines had been highly homozygous prior to the separate strain maintenance.

Inbred maize line PH51H is a yellow, dent maize inbred that is suited as both a male or a female for producing first generation F1 maize hybrids. Inbred maize line PH51H is best adapted to the Northwest, Northcentral, Northeast regions of the United States, Northern and Central Europe and Canada and can be used to produce hybrids from approximately 94-100 relative maturity based on the Comparative Relative Maturity

Rating System for harvest moisture of grain. Inbred maize line PH51H demonstrates very high female yield, very high scatter grain resistance, a small tassel and above average pollen shed as an inbred per se. In hybrid combinations, grown in the area of adaptation for inbred PH51H, inbred PH51H demonstrates high yield with very fast  
5 drydown, heat and seasonal drought tolerance, excellent late season plant health (stay green), above average stalk lodging resistance, above average test weight and grain quality, short plant with low ear placement, strong overall agronomic standability and excellent performance over a wide geographic area.

The inbred has shown uniformity and stability within the limits of environmental  
10 influence for all the traits as described in the Variety Description Information (Table 1) that follows. The inbred has been self-pollinated and ear-rowed a sufficient number of generations with careful attention paid to uniformity of plant type to ensure the homozygosity and phenotypic stability necessary to use in commercial production. The line has been increased both by hand and in isolated fields with continued observation  
15 for uniformity. No variant traits have been observed or are expected in PH51H.

Inbred maize line PH51H, being substantially homozygous, can be reproduced by planting seeds of the line, growing the resulting maize plants under self-pollinating or sib-pollinating conditions with adequate isolation, and harvesting the resulting seed, using techniques familiar to the agricultural arts.



TABLE 1  
VARIETY DESCRIPTION INFORMATION  
VARIETY = PH51H

1. TYPE: (describe intermediate types in Comments section):						
5	2	1=Sweet 2=Dent 3=Flint 4=Flour 5=Pop 6=Ornamental				
2. MATURITY:						
DAYS HEAT UNITS						
10	067	1,225.7	From emergence to 50% of plants in silk			
	067	1,217.3	From emergence to 50% of plants in pollen			
	002	0,063.7	From 10% to 90% pollen shed From 50% silk to harvest at 25% moisture			
3. PLANT:						
15	0,172.3	cm	Plant Height (to tassel tip)	Standard Deviation	Sample Size	
				2.89	15	
	0,061.0	cm	Ear Height (to base of top ear node)	5.20	15	
	0,012.1	cm	Length of Top Ear Internode	1.10	15	
	0.0		Average Number of Tillers	0.01	3	
	1.0		Average Number of Ears per Stalk	0.07	3	
	3.0	Anthocyanin of Brace Roots: 1=Absent 2=Faint 3=Moderate 4=Dark				
4. LEAF:						
20	007.8	cm	Width of Ear Node Leaf	Standard Deviation	Sample Size	
				0.40	15	
	081.3	cm	Length of Ear Node Leaf	2.91	15	
25	05.5		Number of leaves above top ear	1.03	15	
	014.8		Degrees Leaf Angle (measure from 2nd leaf above ear at anthesis to stalk above leaf)	3.10	15	
30	03		Leaf Color	Dark Green	(Munsell code)	7.5GY34
	1.0		Leaf Sheath Pubescence (Rate on scale from 1=none to 9=like peach fuzz)			
			Marginal Waves (Rate on scale from 1=none to 9=many)			
			Longitudinal Creases (Rate on scale from 1=none to 9=many)			
5. TASSEL:						
35	11.9		Number of Primary Lateral Branches	Standard Deviation	Sample Size	
				1.94	15	
	020.1		Branch Angle from Central Spike	9.50	15	
	49.7	cm	Tassel Length (from top leaf collar to tassel tip)	1.70	15	
	3.7		Pollen Shed (rate on scale from 0=male sterile to 9=heavy shed)			
	11		Anther Color	Pink	(Munsell code)	10R46
40	01		Glume Color	Light Green	(Munsell code)	5GY56
	1.0		Bar Glumes (Glume Bands): 1=Absent 2=Present			
	17	cm	Peduncle Length (cm. from top leaf to basal branches)			
	18					
6a. EAR (Unhusked Data):						
45	1		Silk Color (3 days after emergence)	Light Green	(Munsell code)	2.5GY88
	1		Fresh Husk Color (25 days after 50% silking)	Light Green	(Munsell code)	5GY68
	21		Dry Husk Color (65 days after 50% silking)	Buff	(Munsell code)	5Y92
	1		Position of Ear at Dry Husk Stage: 1= Upright 2= Horizontal 3= Pendant			Upright
	7		Husk Tightness (Rate of Scale from 1=very loose to 9=very tight)			
	2		Husk Extension (at harvest): 1=Short (ears exposed) 2=Medium (<8 cm)			
			3=Long (8-10 cm beyond ear tip) 4=Very Long (>10 cm)			Medium
50						

6b. EAR (Husked Ear Data):		Standard Deviation	Sample Size	
5	14 cm Ear Length	1.00	15	
	40 mm Ear Diameter at mid-point	0.00	15	
	108 gm Ear Weight	9.45	15	
	16 Number of Kernel Rows	0.58	15	
	2 Kernel Rows: 1=Indistinct 2=Distinct			Distinct
10	2 Row Alignment: 1=Straight 2=Slightly Curved 3=Spiral			Slightly Curved
	9 cm Shank Length	1.00	15	
	2 Ear Taper: 1=Slight 2= Average 3=Extreme			Average

7. KERNEL (Dried):		Standard Deviation	Sample Size	
15	10 mm Kernel Length	0.00	15	
	8 mm Kernel Width	0.00	15	
	5 mm Kernel Thickness	0.00	15	
	68 % Round Kernels (Shape Grade)	5.00	3	
	1 Aleurone Color Pattern: 1=Homozygous 2=Segregating			Homozygous
20	7 Aleurone Color Yellow	(Munsell code)		10YR714
	7 Hard Endosperm Color Yellow	(Munsell code)		10YR712
	3 Endosperm Type: Normal Starch			
	1=Sweet (Su1) 2=Extra Sweet (sh2) 3=Normal Starch			
	4=High Amylose Starch 5=Waxy Starch 6=High Protein			
25	7=High Lysine 8=Super Sweet (se) 9=High Oil			
	10=Other _____			
	25 gm Weight per 100 Kernels (unsized sample)	1.00	3	

8. COB:		Standard Deviation	Sample Size	
30	22 mm Cob Diameter at mid-point	0.58	15	
	14 Cob Color Red	(Munsell code)		10R38

9. DISEASE RESISTANCE (Rate from 1 (most susceptible) to 9 (most resistant); leave blank if not tested; leave Race or Strain Options blank if polygenic):

A. Leaf Blights, Wilts, and Local Infection Diseases	
35	Anthrachnose Leaf Blight ( <i>Colletotrichum graminicola</i> )
	Common Rust ( <i>Puccinia sorghi</i> )
	Common Smut ( <i>Ustilago maydis</i> )
	6 Eyespot ( <i>Kabatiella zeae</i> )
	7 Goss's Wilt ( <i>Clavibacter michiganense</i> spp. <i>nebraskense</i> )
40	4 Gray Leaf Spot ( <i>Cercospora zeae-maydis</i> )
	Helminthosporium Leaf Spot ( <i>Bipolaris zeicola</i> ) Race _____
	6 Northern Leaf Blight ( <i>Exserohilum turcicum</i> ) Race _____
	Southern Leaf Blight ( <i>Bipolaris maydis</i> ) Race _____
	Southern Rust ( <i>Puccinia polysora</i> )
45	6 Stewart's Wilt ( <i>Erwinia stewartii</i> )
	Other (Specify) _____
B. Systemic Diseases	
50	Corn Lethal Necrosis (MCMV and MDMV)
	Head Smut ( <i>Sphacelotheca reiliana</i> )
	Maize Chlorotic Dwarf Virus (MDV)
	Maize Chlorotic Mottle Virus (MCMV)
	Maize Dwarf Mosaic Virus (MDMV)
	Sorghum Downy Mildew of Corn ( <i>Peronosclerospora sorghi</i> )
	Other (Specify) _____

C. Stalk Rots

- 5                   3    Anthrachnose Stalk Rot (*Colletotrichum graminicola*)  
                       Diplodia Stalk Rot (*Stenocarpella maydis*)  
                       Fusarium Stalk Rot (*Fusarium moniliforme*)  
                       Gibberella Stalk Rot (*Gibberella zeae*)  
                       Other (Specify) \_\_\_\_\_

D. Ear and Kernel Rots

- 10                   4    Aspergillus Ear and Kernel Rot (*Aspergillus flavus*)  
                       Diplodia Ear Rot (*Stenocarpella maydis*)  
                       4    Fusarium Ear and Kernel Rot (*Fusarium moniliforme*)  
                       4    Gibberella Ear Rot (*Gibberella zeae*)  
                       Other (Specify) \_\_\_\_\_

10. INSECT RESISTANCE (Rate from 1 (most susceptible) to 9 (most resistant);  
 (leave blank if not tested) :

- 15                   Banks grass Mite (*Oligonychus pratensis*)  
                       Corn Worm (*Helicoverpa zea*)  
                       Leaf Feeding  
                       Silk Feeding  
                       mg larval wt.  
 20                   Ear Damage  
                       Corn Leaf Aphid (*Rhopalosiphum maidis*)  
                       Corn Sap Beetle (*Carpophilus dimidiatus*)  
                       European Corn Borer (*Ostrinia nubilalis*)  
                       1st Generation (Typically Whorl Leaf Feeding)  
 25                   2nd Generation (Typically Leaf Sheath-Collar Feeding)  
                       Stalk Tunneling  
                       cm tunneled/plant  
                       Fall Armyworm (*Spodoptera frugiperda*)  
                       Leaf Feeding  
 30                   Silk Feeding  
                       mg larval wt.  
                       Maize Weevil (*Sitophilus zeamais*)  
                       Northern Rootworm (*Diabrotica barberi*)  
                       Southern Rootworm (*Diabrotica undecimpunctata*)  
 35                   Southwestern Corn Borer (*Diatraea grandiosella*)  
                       Leaf Feeding  
                       Stalk Tunneling  
                       cm tunneled/plant  
                       Two-spotted Spider Mite (*Tetranychus urticae*)  
 40                   Western Rootworm (*Diabrotica virgifera virgifera*)  
                       Other (Specify) \_\_\_\_\_

11. AGRONOMIC TRAITS:

- 5                   Staygreen (at 65 days after anthesis) (Rate on a scale from 1=worst to 9=excellent)  
 0.0               % Dropped Ears (at 65 days after anthesis)  
 45               % Pre-anthesis Brittle Snapping  
                   % Pre-anthesis Root Lodging  
                   17.4   Post-anthesis Root Lodging (at 65 days after anthesis)  
                   5.759   Kg/ha Yield (at 12-13% grain moisture)

\*In interpreting the foregoing color designations, reference may be made to the Munsell Glossy Book of Color, a standard color reference

### **Further Embodiments of the Invention**

This invention also is directed to methods for producing a maize plant by crossing a first parent maize plant with a second parent maize plant wherein either the first or second parent maize plant is an inbred maize plant of the line PH51H. Further, both first and second parent maize plants can come from the inbred maize line PH51H. Still further, this invention also is directed to methods for producing an inbred maize line PH51H-derived maize plant by crossing inbred maize line PH51H with a second maize plant and growing the progeny seed, and repeating the crossing and growing steps with the inbred maize line PH51H-derived plant from 0 to 5 times. Thus, any such methods using the inbred maize line PH51H are part of this invention: selfing, backcrosses, hybrid production, crosses to populations, and the like. All plants produced using inbred maize line PH51H as a parent are within the scope of this invention, including plants derived from inbred maize line PH51H. Advantageously, the inbred maize line is used in crosses with other, different, maize inbreds to produce first generation (F<sub>1</sub>) maize hybrid seeds and plants with superior characteristics.

A further embodiment of the invention is a single gene conversion or introgression of the maize plant disclosed herein in which the gene or genes of interest (encoding the desired trait) are introduced through traditional (non-transformation) breeding techniques, such as backcrossing (Hallauer *et al*, 1988). One or more genes may be introduced using these techniques. Desired traits transferred through this process include, but are not limited to, waxy starch, nutritional enhancements, industrial enhancements, disease resistance, insect resistance, herbicide resistance and yield enhancements. The gene of interest is transferred from the donor parent to the recurrent parent, in this case, the maize plant disclosed herein. These single gene traits may result from either the transfer of a dominant allele or a recessive allele. Selection of progeny containing the trait of interest is done by direct selection for a trait associated with a dominant allele. Selection of progeny for a trait that is transferred via a recessive allele, such as the waxy starch characteristic, requires growing and selfing the first backcross to determine which plants carry the recessive alleles. Recessive traits may require additional progeny testing in successive backcross generations to determine the presence of the gene of interest.

It should be understood that the inbred can, through routine manipulation of cytoplasmic or other factors, be produced in a male-sterile form. Such embodiments are also contemplated within the scope of the present claims.

As used herein, the term plant includes plant cells, plant protoplasts, plant cell tissue cultures from which maize plants can be regenerated, plant calli, plant clumps, and plant cells that are intact in plants or parts of plants, such as embryos, pollen, ovules, seeds, flowers, kernels, ears, cobs, leaves, husks, stalks, roots, root tips, anthers, silk and the like.

Duncan, Williams, Zehr, and Widholm, *Planta* (1985) 165:322-332 reflects that 97% of the plants cultured that produced callus were capable of plant regeneration. Subsequent experiments with both inbreds and hybrids produced 91% regenerable callus that produced plants. In a further study in 1988, Songstad, Duncan & Widholm in *Plant Cell Reports* (1988), 7:262-265 reports several media additions that enhance regenerability of callus of two inbred lines. Other published reports also indicated that "nontraditional" tissues are capable of producing somatic embryogenesis and plant regeneration. K.P. Rao, et al., *Maize Genetics Cooperation Newsletter*, 60:64-65 (1986), refers to somatic embryogenesis from glume callus cultures and B.V. Conger, et al., *Plant Cell Reports*, 6:345-347 (1987) indicates somatic embryogenesis from the tissue cultures of maize leaf segments. Thus, it is clear from the literature that the state of the art is such that these methods of obtaining plants are, and were, "conventional" in the sense that they are routinely used and have a very high rate of success.

Tissue culture of maize is described in European Patent Application, publication 160,390, incorporated herein by reference. Maize tissue culture procedures are also described in Green and Rhodes, "Plant Regeneration in Tissue Culture of Maize," *Maize for Biological Research* (Plant Molecular Biology Association, Charlottesville, Virginia 1982, at 367-372) and in Duncan, et al., "The Production of Callus Capable of Plant Regeneration from Immature Embryos of Numerous *Zea Mays* Genotypes," 165 *Planta* 322-332 (1985). Thus, another aspect of this invention is to provide cells which upon growth and differentiation produce maize plants having the physiological and morphological characteristics of inbred line PH51H.

The utility of inbred maize line PH51H also extends to crosses with other species. Commonly, suitable species will be of the family Gramineae, and especially of the genera *Zea*, *Tripsacum*, *Coix*, *Schlerachne*, *Polytoca*, *Chionachne*, and *Trilobachne*, of the tribe Maydeae. Potentially suitable for crosses with PH51H may be the various varieties of grain sorghum, *Sorghum bicolor* (L.) Moench.

#### **Transformation of Maize**

With the advent of molecular biological techniques that have allowed the

isolation and characterization of genes that encode specific protein products, scientists in the field of plant biology developed a strong interest in engineering the genome of plants to contain and express foreign genes, or additional, or modified versions of native or endogenous genes (perhaps driven by different promoters) in order to alter the traits of a plant in a specific manner. Such foreign, additional and/or modified genes are referred to herein collectively as "transgenes". Over the last fifteen to twenty years several methods for producing transgenic plants have been developed, and the present invention, in particular embodiments, also relates to transformed versions of the claimed inbred maize line PH51H.

Plant transformation involves the construction of an expression vector which will function in plant cells. Such a vector comprises DNA comprising a gene under control of or operatively linked to a regulatory element (for example, a promoter). The expression vector may contain one or more such operably linked gene/regulatory element combinations. The vector(s) may be in the form of a plasmid, and can be used, alone or in combination with other plasmids, to provide transformed maize plants, using transformation methods as described below to incorporate transgenes into the genetic material of the maize plant(s).

### **Expression Vectors For Maize Transformation**

#### **Marker Genes**

Expression vectors include at least one genetic marker, operably linked to a regulatory element (a promoter, for example) that allows transformed cells containing the marker to be either recovered by negative selection, *i.e.* inhibiting growth of cells that do not contain the selectable marker gene, or by positive selection, *i.e.*, screening for the product encoded by the genetic marker. Many commonly used selectable marker genes for plant transformation are well known in the transformation arts, and include, for example, genes that code for enzymes that metabolically detoxify a selective chemical agent which may be an antibiotic or a herbicide, or genes that encode an altered target which is insensitive to the inhibitor. A few positive selection methods are also known in the art.

One commonly used selectable marker gene for plant transformation is the neomycin phosphotransferase II (*nptII*) gene, isolated from transposon Tn5, which when placed under the control of plant regulatory signals confers resistance to kanamycin. Fraley *et al.*, *Proc. Natl. Acad. Sci. U.S.A.*, 80: 4803 (1983). Another commonly used selectable marker gene is the hygromycin phosphotransferase gene which confers

resistance to the antibiotic hygromycin. Vanden Elzen *et al.*, *Plant Mol. Biol.*, 5: 299 (1985).

Additional selectable marker genes of bacterial origin that confer resistance to antibiotics include gentamycin acetyl transferase, streptomycin phosphotransferase, aminoglycoside- 3' -adenyl transferase, the bleomycin resistance determinant. Hayford *et al.*, *Plant Physiol.* 86: 1216 (1988), Jones *et al.*, *Mol. Gen. Genet.*, 210: 86 (1987), Svab *et al.*, *Plant Mol. Biol.*, 14: 197 (1990), Hille *et al.*, *Plant Mol. Biol.* 7: 171 (1986). Other selectable marker genes confer resistance to herbicides such as glyphosate, glufosinate or broxynil. Comai *et al.*, *Nature* 317: 741-744 (1985), Gordon-Kamm *et al.*, *Plant Cell* 2: 603-618 (1990) and Stalker *et al.*, *Science* 242: 419-423 (1988).

Other selectable marker genes for plant transformation are not of bacterial origin. These genes include, for example, mouse dihydrofolate reductase, plant 5 - enolpyruvylshikimate-3 -phosphate synthase and plant acetolactate synthase. Eichholtz *et al.*, *Somatic Cell Mol. Genet.* 13: 67 (1987), Shah *et al.*, *Science* 233: 478 (1986), Charest *et al.*, *Plant Cell Rep.* 8: 643 (1990).

Another class of marker genes for plant transformation require screening of presumptively transformed plant cells rather than direct genetic selection of transformed cells for resistance to a toxic substance such as an antibiotic. These genes are particularly useful to quantify or visualize the spatial pattern of expression of a gene in specific tissues and are frequently referred to as reporter genes because they can be fused to a gene or gene regulatory sequence for the investigation of gene expression. Commonly used genes for screening presumptively transformed cells include  $\beta$ -glucuronidase (*GUS*),  $\beta$ -galactosidase, luciferase and chloramphenicol acetyltransferase. Jefferson, R.A., *Plant Mol. Biol. Rep.* 5: 387 (1987), Teeri *et al.*, *EMBO J.* 8: 343 (1989), Koncz *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* 84:131 (1987), De Block *et al.*, *EMBO J.* 3: 1681 (1984). Another approach to the identification of relatively rare transformation events has been use of a gene that encodes a dominant constitutive regulator of the *Zea mays* anthocyanin pigmentation pathway. Ludwig *et al.*, *Science* 247: 449 (1990).

Recently, *in vivo* methods for visualizing GUS activity that do not require destruction of plant tissue have been made available. Molecular Probes Publication 2908, Imagen Green™, p. 1-4 (1993) and Naleway *et al.*, *J. Cell Biol.* 115: 151a (1991). However, these *in vivo* methods for visualizing GUS activity have not proven useful for recovery of transformed cells because of low sensitivity, high fluorescent backgrounds,

and limitations associated with the use of luciferase genes as selectable markers.

More recently, a gene encoding Green Fluorescent Protein (GFP) has been utilized as a marker for gene expression in prokaryotic and eukaryotic cells. Chalfie *et al.*, *Science* 263: 802 (1994). GFP and mutants of GFP may be used as screenable markers.

### **Promoters**

Genes included in expression vectors must be driven by a nucleotide sequence comprising a regulatory element, for example, a promoter. Several types of promoters are now well known in the transformation arts, as are other regulatory elements that can be used alone or in combination with promoters.

As used herein "promoter" includes reference to a region of DNA upstream from the start of transcription and involved in recognition and binding of RNA polymerase and other proteins to initiate transcription. A "plant promoter" is a promoter capable of initiating transcription in plant cells. Examples of promoters under developmental control include promoters that preferentially initiate transcription in certain tissues, such as leaves, roots, seeds, fibers, xylem vessels, tracheids, or sclerenchyma. Such promoters are referred to as "tissue-preferred". Promoters which initiate transcription only in certain tissues are referred to as "tissue-specific". A "cell type" specific promoter primarily drives expression in certain cell types in one or more organs, for example, vascular cells in roots or leaves. An "inducible" promoter is a promoter which is under environmental control. Examples of environmental conditions that may effect transcription by inducible promoters include anaerobic conditions or the presence of light. Tissue-specific, tissue-preferred, cell type specific, and inducible promoters constitute the class of "non-constitutive" promoters. A "constitutive" promoter is a promoter which is active under most environmental conditions.

#### **A. Inducible Promoters**

An inducible promoter is operably linked to a gene for expression in maize. Optionally, the inducible promoter is operably linked to a nucleotide sequence encoding a signal sequence which is operably linked to a gene for expression in maize. With an inducible promoter the rate of transcription increases in response to an inducing agent.

Any inducible promoter can be used in the instant invention. See Ward *et al.* *Plant Mol. Biol.* 22: 361-366 (1993). Exemplary inducible promoters include, but are not limited to, that from the ACEI system which responds to copper (Mett *et al.* *PNAS* 90: 4567-4571 (1993)); In2 gene from maize which responds to benzenesulfonamide



herbicide safeners (Hershey *et al.*, *Mol. Gen. Genetics* 227: 229-237 (1991) and Gatz *et al.*, *Mol. Gen. Genetics* 243: 32-38 (1994)) or Tet repressor from Tn10 (Gatz *et al.*, *Mol. Gen. Genet.* 227: 229-237 (1991). A particularly preferred inducible promoter is a promoter that responds to an inducing agent to which plants do not normally respond.

5 An exemplary inducible promoter is the inducible promoter from a steroid hormone gene, the transcriptional activity of which is induced by a glucocorticosteroid hormone. Schena *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* 88: 0421 (1991).

#### **B. Constitutive Promoters**

A constitutive promoter is operably linked to a gene for expression in maize or

10 the constitutive promoter is operably linked to a nucleotide sequence encoding a signal sequence which is operably linked to a gene for expression in maize.

Many different constitutive promoters can be utilized in the instant invention. Exemplary constitutive promoters include, but are not limited to, the promoters from plant viruses such as the 35S promoter from CaMV (Odell *et al.*, *Nature* 313: 810-812

15 (1985) and the promoters from such genes as rice actin (McElroy *et al.*, *Plant Cell* 2: 163-171 (1990)); ubiquitin (Christensen *et al.*, *Plant Mol. Biol.* 12: 619-632 (1989) and Christensen *et al.*, *Plant Mol. Biol.* 18: 675-689 (1992)); pEMU (Last *et al.*, *Theor. Appl. Genet.* 81: 581-588 (1991)); MAS (Velten *et al.*, *EMBO J.* 3: 2723-2730 (1984)) and maize H3 histone (Lepetit *et al.*, *Mol. Gen. Genet.* 231: 276-285 (1992) and Atanassova

20 *et al.*, *Plant Journal* 2 (3): 291-300 (1992)).

The ALS promoter, a XbaI/NcoI fragment 5' to the *Brassica napus* ALS3 structural gene (or a nucleotide sequence that has substantial sequence similarity to said XbaI/NcoI fragment), represents a particularly useful constitutive promoter. See PCT application WO96/30530.

#### **C. Tissue-specific or Tissue-Preferred Promoters**

A tissue-specific promoter is operably linked to a gene for expression in maize. Optionally, the tissue-specific promoter is operably linked to a nucleotide sequence encoding a signal sequence which is operably linked to a gene for expression in maize. Plants transformed with a gene of interest operably linked to a tissue-specific promoter

30 produce the protein product of the transgene exclusively, or preferentially, in a specific tissue.

Any tissue-specific or tissue-preferred promoter can be utilized in the instant invention. Exemplary tissue-specific or tissue-preferred promoters include, but are not limited to, a root-preferred promoter, such as that from the phaseolin gene (Murai *et al.*,

Science 23: 476-482 (1983) and Sengupta-Gopalan *et al.*, *Proc. Natl. Acad. Sci. USA* 82: 3320-3324 (1985)); a leaf-specific and light-induced promoter such as that from *cab* or *rubisco* (Simpson *et al.*, *EMBO J.* 4(11): 2723-2729 (1985) and Timko *et al.*, *Nature* 318: 579-582 (1985)); an anther-specific promoter such as that from *LAT52* (Twell *et al.*, *Mol. Gen. Genet.* 217: 240-245 (1989)); a pollen-specific promoter such as that from *Zm13* (Guerrero *et al.*, *Mol. Gen. Genet.* 224: 161-168 (1993)) or a microspore-preferred promoter such as that from *apg* (Twell *et al.*, *Sex. Plant Reprod.* 6: 217-224 (1993)).

### **Signal Sequences For Targeting Proteins to Subcellular Compartments**

Transport of protein produced by transgenes to a subcellular compartment such as the chloroplast, vacuole, peroxisome, glyoxysome, cell wall or mitochondrion, or for secretion into the apoplast, is accomplished by means of operably linking the nucleotide sequence encoding a signal sequence to the 5' and/or 3' region of a gene encoding the protein of interest. Targeting sequences at the 5' and/or 3' end of the structural gene may determine, during protein synthesis and processing, where the encoded protein is ultimately compartmentalized. The presence of a signal sequence directs a polypeptide to either an intracellular organelle or subcellular compartment or for secretion to the apoplast. Many signal sequences are known in the art. See, for example, Becker *et al.*, *Plant Mol. Biol.* 20: 49 (1992), Close, P.S., Master's Thesis, Iowa State University (1993), Knox, C., *et al.*, "Structure and Organization of Two Divergent Alpha-Amylase Genes From Barley", *Plant Mol. Biol.* 9: 3-17 (1987), Lerner *et al.*, *Plant Physiol.* 91: 124-129 (1989), Fontes *et al.*, *Plant Cell* 3: 483-496 (1991), Matsuoka *et al.*, *Proc. Natl. Acad. Sci.* 88: 834 (1991), Gould *et al.*, *J. Cell Biol.* 108: 1657 (1989), Creissen *et al.*, *Plant J.* 2: 129 (1991), Kalderon, D., Robers, B., Richardson, W., and Smith A., "A short amino acid sequence able to specify nuclear location", *Cell* 39: 499-509 (1984), Stiefel, V., Ruiz-Avila, L., Raz R., Valles M., Gomez J., Pages M., Martinez-Izquierdo J., Ludevid M., Landale J., Nelson T., and Puigdomenech P., "Expression of a maize cell wall hydroxyproline-rich glycoprotein gene in early leaf and root vascular differentiation", *Plant Cell* 2: 785-793 (1990).

### **Foreign Protein Genes and Agronomic Genes**

With transgenic plants according to the present invention, a foreign protein can be produced in commercial quantities. Thus, techniques for the selection and propagation of transformed plants, which are well understood in the art, yield a plurality of transgenic plants which are harvested in a conventional manner, and a foreign protein then can be extracted from a tissue of interest or from total biomass. Protein

extraction from plant biomass can be accomplished by known methods which are discussed, for example, by Heney and Orr, *Anal. Biochem.* 114: 92-6 (1981).

According to a preferred embodiment, the transgenic plant provided for commercial production of foreign protein is maize. In another preferred embodiment, the biomass of interest is seed. For the relatively small number of transgenic plants that show higher levels of expression, a genetic map can be generated, primarily via conventional Restriction Fragment Length Polymorphisms (RFLP), Polymerase Chain Reaction (PCR) analysis, and Simple Sequence Repeats (SSR) which identifies the approximate chromosomal location of the integrated DNA molecule. For exemplary methodologies in this regard, see Glick and Thompson, *METHODS IN PLANT MOLECULAR BIOLOGY AND BIOTECHNOLOGY* 269-284 (CRC Press, Boca Raton, 1993). Map information concerning chromosomal location is useful for proprietary protection of a subject transgenic plant. If unauthorized propagation is undertaken and crosses made with other germplasm, the map of the integration region can be compared to similar maps for suspect plants, to determine if the latter have a common parentage with the subject plant. Map comparisons would involve hybridizations, RFLP, PCR, SSR and sequencing, all of which are conventional techniques.

Likewise, by means of the present invention, agronomic genes can be expressed in transformed plants. More particularly, plants can be genetically engineered to express various phenotypes of agronomic interest. Exemplary genes implicated in this regard include, but are not limited to, those categorized below.

**1. Genes That Confer Resistance To Pests or Disease And That Encode:**

(A) Plant disease resistance genes. Plant defenses are often activated by specific interaction between the product of a disease resistance gene (R) in the plant and the product of a corresponding avirulence (Avr) gene in the pathogen. A plant variety can be transformed with cloned resistance gene to engineer plants that are resistant to specific pathogen strains. See, for example Jones et al., *Science* 266: 789 (1994) (cloning of the tomato Cf-9 gene for resistance to *Cladosporium fulvum*); Martin et al., *Science* 262: 1432 (1993) (tomato *Pto* gene for resistance to *Pseudomonas syringae* pv. tomato encodes a protein kinase); Mindrinos et al., *Cell* 78: 1089 (1994) (*Arabidopsis RSP2* gene for resistance to *Pseudomonas syringae*).

(B) A *Bacillus thuringiensis* protein, a derivative thereof or a synthetic polypeptide modeled thereon. See, for example, Geiser et al., *Gene* 48: 109 (1986), who disclose the cloning and nucleotide sequence of a *Bt*  $\delta$ -endotoxin gene. Moreover,

DNA molecules encoding  $\delta$ -endotoxin genes can be purchased from American Type Culture Collection (Rockville, MD), for example, under ATCC Accession Nos. 40098, 67136, 31995 and 31998.

(C) A lectin. See, for example, the disclosure by Van Damme *et al.*, *Plant Molec. Biol.* 24: 25 (1994), who disclose the nucleotide sequences of several *Clivia miniata* mannose-binding lectin genes.

(D) A vitamin-binding protein such as avidin. See PCT application US93/06487 the contents of which are hereby incorporated by. The application teaches the use of avidin and avidin homologues as larvicides against insect pests.

(E) An enzyme inhibitor, for example, a protease inhibitor or an amylase inhibitor. See, for example, Abe *et al.*, *J. Biol. Chem.* 262: 16793 (1987) (nucleotide sequence of rice cysteine proteinase inhibitor), Huub *et al.*, *Plant Molec. Biol.* 21: 985 (1993) (nucleotide sequence of cDNA encoding tobacco proteinase inhibitor i), and Sumitani *et al.*, *Biosci. Biotech. Biochem.* 57: 1243 (1993) (nucleotide sequence of *Streptomyces nitrosporeus*  $\alpha$ -amylase inhibitor).

(F) An insect-specific hormone or pheromone such as an ecdysteroid and juvenile hormone, a variant thereof, a mimetic based thereon, or an antagonist or agonist thereof. See, for example, the disclosure by Hammock *et al.*, *Nature* 344: 458 (1990), of baculovirus expression of cloned juvenile hormone esterase, an inactivator of juvenile hormone.

(G) An insect-specific peptide or neuropeptide which, upon expression, disrupts the physiology of the affected pest. For example, see the disclosures of Regan, *J. Biol. Chem.* 269: 9 (1994) (expression cloning yields DNA coding for insect diuretic hormone receptor), and Pratt *et al.*, *Biochem. Biophys. Res. Comm.* 163: 1243 (1989) (an allostatin is identified in *Diploptera puntata*). See also U.S. patent No.5,266,317 to Tomalski *et al.*, who disclose genes encoding insect-specific, paralytic neurotoxins.

(H) An insect-specific venom produced in nature by a snake, a wasp, *etc.* For example, see Pang *et al.*, *Gene* 116: 165 (1992), for disclosure of heterologous expression in plants of a gene coding for a scorpion insectotoxic peptide.

(I) An enzyme responsible for an hyperaccumulation of a monerpene, a sesquiterpene, a steroid, hydroxamic acid, a phenylpropanoid derivative or another non-protein molecule with insecticidal activity.

(J) An enzyme involved in the modification, including the post-translational

modification, of a biologically active molecule; for example, a glycolytic enzyme, a proteolytic enzyme, a lipolytic enzyme, a nuclease, a cyclase, a transaminase, an esterase, a hydrolase, a phosphatase, a kinase, a phosphorylase, a polymerase, an elastase, a chitinase and a glucanase, whether natural or synthetic. See PCT application WO 93/02197 in the name of Scott *et al.*, which discloses the nucleotide sequence of a callase gene. DNA molecules which contain chitinase-encoding sequences can be obtained, for example, from the ATCC under Accession Nos. 39637 and 67152. See also Kramer *et al.*, *Insect Biochem. Molec. Biol.* 23: 691 (1993), who teach the nucleotide sequence of a cDNA encoding tobacco hookworm chitinase, and Kawalleck *et al.*, *Plant Molec. Biol.* 21: 673 (1993), who provide the nucleotide sequence of the parsley *ubi4-2* polyubiquitin gene.

(K) A molecule that stimulates signal transduction. For example, see the disclosure by Botella *et al.*, *Plant Molec. Biol.* 24: 757 (1994), of nucleotide sequences for mung bean calmodulin cDNA clones, and Griess *et al.*, *Plant Physiol.* 104: 1467 (1994), who provide the nucleotide sequence of a maize calmodulin cDNA clone.

(L) A hydrophobic moment peptide. See PCT application WO95/16776 (disclosure of peptide derivatives of Tachyplesin which inhibit fungal plant pathogens) and PCT application WO95/18855 (teaches synthetic antimicrobial peptides that confer disease resistance), the respective contents of which are hereby incorporated by reference.

(M) A membrane permease, a channel former or a channel blocker. For example, see the disclosure by Jaynes *et al.*, *Plant Sci.* 89: 43 (1993), of heterologous expression of a cecropin- $\beta$  lytic peptide analog to render transgenic tobacco plants resistant to *Pseudomonas solanacearum*.

(N) A viral-invasive protein or a complex toxin derived therefrom. For example, the accumulation of viral coat proteins in transformed plant cells imparts resistance to viral infection and/or disease development effected by the virus from which the coat protein gene is derived, as well as by related viruses. See Beachy *et al.*, *Ann. Rev. Phytopathol.* 28: 451 (1990). Coat protein-mediated resistance has been conferred upon transformed plants against alfalfa mosaic virus, cucumber mosaic virus, tobacco streak virus, potato virus X, potato virus Y, tobacco etch virus, tobacco rattle virus and tobacco mosaic virus. *Id.*

(O) An insect-specific antibody or an immunotoxin derived therefrom. Thus, an antibody targeted to a critical metabolic function in the insect gut would inactivate an

affected enzyme, killing the insect. Cf. Taylor *et al.*, Abstract #497, SEVENTH INT'L SYMPOSIUM ON MOLECULAR PLANT-MICROBE INTERACTIONS (Edinburgh, Scotland, 1994) (enzymatic inactivation in transgenic tobacco via production of single-chain antibody fragments).

5 (P) A virus-specific antibody. See, for example, Tavladoraki *et al.*, *Nature* 366: 469 (1993), who show that transgenic plants expressing recombinant antibody genes are protected from virus attack.

(Q) A developmental-arrestive protein produced in nature by a pathogen or a parasite. Thus, fungal endo  $\alpha$ -1,4-D-polygalacturonases facilitate fungal colonization  
10 and plant nutrient release by solubilizing plant cell wall homo- $\alpha$ -1,4-D-galacturonase. See Lamb *et al.*, *Bio/Technology* 10: 1436 (1992). The cloning and characterization of a gene which encodes a bean endopolygalacturonase-inhibiting protein is described by Toubart *et al.*, *Plant J.* 2: 367 (1992).

(R) A developmental-arrestive protein produced in nature by a plant. For  
15 example, Logemann *et al.*, *Bio/Technology* 10: 305 (1992), have shown that transgenic plants expressing the barley ribosome-inactivating gene have an increased resistance to fungal disease.

## 2. Genes That Confer Resistance To A Herbicide, For Example:

(A) A herbicide that inhibits the growing point or meristem, such as an  
20 imidazalinone or a sulfonylurea. Exemplary genes in this category code for mutant ALS and AHAS enzyme as described, for example, by Lee *et al.*, *EMBO J.* 7: 1241 (1988), and Miki *et al.*, *Theor. Appl. Genet.* 80: 449 (1990), respectively.

(B) Glyphosate (resistance imparted by mutant 5-enolpyruvyl-3-phosphikimate synthase (EPSP) and *aroA* genes, respectively) and other phosphono compounds  
25 such as glufosinate (phosphinothricin acetyl transferase (PAT) and *Streptomyces hygroscopicus* phosphinothricin acetyl transferase (*bar*) genes), and pyridinoxy or phenoxy proprionic acids and cyclohexones (ACCase inhibitor-encoding genes). See, for example, U.S. patent No. 4,940,835 to Shah *et al.*, which discloses the nucleotide sequence of a form of EPSP which can confer glyphosate resistance. A DNA molecule  
30 encoding a mutant *aroA* gene can be obtained under ATCC accession No. 39256, and the nucleotide sequence of the mutant gene is disclosed in U.S. patent No. 4,769,061 to Comai. European patent application No. 0 333 033 to Kumada *et al.* and U.S. patent No. 4,975,374 to Goodman *et al.* disclose nucleotide sequences of glutamine synthetase genes which confer resistance to herbicides such as L-phosphinothricin.

The nucleotide sequence of a phosphinothricin-acetyl-transferase gene is provided in European application No. 0 242 246 to Leemans *et al.* De Greef *et al.*, *Bio/Technology* 7: 61 (1989), describe the production of transgenic plants that express chimeric *bar* genes coding for phosphinothricin acetyl transferase activity. Exemplary of genes  
5 conferring resistance to phenoxy proprionic acids and cyclohexones, such as sethoxydim and haloxyfop, are the *Acc1-S1*, *Acc1-S2* and *Acc1-S3* genes described by Marshall *et al.*, *Theor. Appl. Genet.* 83: 435 (1992).

(C) A herbicide that inhibits photosynthesis, such as a triazine (*psbA* and *gs+* genes) and a benzonitrile (nitrilase gene). Przibilla *et al.*, *Plant Cell* 3: 169 (1991),  
10 describe the transformation of *Chlamydomonas* with plasmids encoding mutant *psbA* genes. Nucleotide sequences for nitrilase genes are disclosed in U.S. patent No. 4,810,648 to Stalker, and DNA molecules containing these genes are available under ATCC Accession Nos. 53435, 67441 and 67442. Cloning and expression of DNA coding for a glutathione S-transferase is described by Hayes *et al.*, *Biochem. J.* 285:  
15 173 (1992).

**3. Genes That Confer Or Contribute To A Value-Added Trait, Such As:**

(A) Modified fatty acid metabolism, for example, by transforming a plant with an antisense gene of stearoyl-ACP desaturase to increase stearic acid content of the plant. See Knultzon *et al.*, *Proc. Natl. Acad. Sci. USA* 89: 2624 (1992).

20 (B) Decreased phytate content

(1) Introduction of a phytase-encoding gene would enhance breakdown of phytate, adding more free phosphate to the transformed plant. For example, see Van Hartingsveldt *et al.*, *Gene* 127: 87 (1993), for a disclosure of the nucleotide sequence of an *Aspergillus niger* phytase gene.

25 (2) A gene could be introduced that reduces phytate content. In maize, this, for example, could be accomplished, by cloning and then reintroducing DNA associated with the single allele which is responsible for maize mutants characterized by low levels of phytic acid. See Raboy *et al.*, *Maydica* 35: 383 (1990).

(C) Modified carbohydrate composition effected, for example, by  
30 transforming plants with a gene coding for an enzyme that alters the branching pattern of starch. See Shiroza *et al.*, *J. Bacteriol.* 170: 810 (1988) (nucleotide sequence of *Streptococcus mutans* fructosyltransferase gene), Steinmetz *et al.*, *Mol. Gen. Genet.* 200: 220 (1985) (nucleotide sequence of *Bacillus subtilis* levansucrase gene), Pen *et al.*, *Bio/Technology* 10: 292 (1992) (production of transgenic plants that express *Bacillus*

*licheniformis*  $\alpha$ -amylase), Elliot *et al.*, *Plant Molec. Biol.* 21: 515 (1993) (nucleotide sequences of tomato invertase genes), Sogaard *et al.*, *J. Biol. Chem.* 268: 22480 (1993) (site-directed mutagenesis of barley  $\alpha$ -amylase gene), and Fisher *et al.*, *Plant Physiol.* 102: 1045 (1993) (maize endosperm starch branching enzyme II).

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## Methods for Maize Transformation

Numerous methods for plant transformation have been developed, including biological and physical, plant transformation protocols. See, for example, Miki *et al.*, "Procedures for Introducing Foreign DNA into Plants" in *Methods in Plant Molecular Biology and Biotechnology*, Glick, B.R. and Thompson, J.E. Eds. (CRC Press, Inc., Boca Raton, 1993) pages 67-88. In addition, expression vectors and *in vitro* culture methods for plant cell or tissue transformation and regeneration of plants are available. See, for example, Gruber *et al.*, "Vectors for Plant Transformation" in *Methods in Plant Molecular Biology and Biotechnology*, Glick, B.R. and Thompson, J.E. Eds. (CRC Press, Inc., Boca Raton, 1993) pages 89-119.

### A. *Agrobacterium*-mediated Transformation

One method for introducing an expression vector into plants is based on the natural transformation system of *Agrobacterium*. See, for example, Horsch *et al.*, *Science* 227: 1229 (1985). *A. tumefaciens* and *A. rhizogenes* are plant pathogenic soil bacteria which genetically transform plant cells. The Ti and Ri plasmids of *A. tumefaciens* and *A. rhizogenes*, respectively, carry genes responsible for genetic transformation of the plant. See, for example, Kado, C.I., *Crit. Rev. Plant. Sci.* 10: 1 (1991). Descriptions of *Agrobacterium* vector systems and methods for *Agrobacterium*-mediated gene transfer are provided by Gruber *et al.*, *supra*, Miki *et al.*, *supra*, and Moloney *et al.*, *Plant Cell Reports* 8: 238 (1989). See also, U.S. Patent No. 5,591,616, issued Jan. 7, 1997.

### B. Direct Gene Transfer

Despite the fact the host range for *Agrobacterium*-mediated transformation is broad, some major cereal crop species and gymnosperms have generally been recalcitrant to this mode of gene transfer, even though some success has recently been achieved in rice and maize. Hiei *et al.*, *The Plant Journal* 6: 271-282 (1994); U.S. Patent No. 5,591,616, issued Jan. 7, 1997. Several methods of plant transformation, collectively referred to as direct gene transfer, have been developed as an alternative to *Agrobacterium*-mediated transformation.



A generally applicable method of plant transformation is microprojectile-mediated transformation wherein DNA is carried on the surface of microprojectiles measuring 1 to 4  $\mu\text{m}$ . The expression vector is introduced into plant tissues with a biolistic device that accelerates the microprojectiles to speeds of 300 to 600 m/s which is sufficient to penetrate plant cell walls and membranes. Sanford *et al.*, *Plant Sci. Technol.* 5: 27 (1987), Sanford, J.C., *Trends Biotech.* 6: 299 (1988), Klein *et al.*, *Bio/Technology* 6: 559-563 (1988), Sanford, J.C., *Physiol Plant* 79: 206 (1990), Klein *et al.*, *Biotechnology* 10: 268 (1992). In maize, several target tissues can be bombarded with DNA-coated microprojectiles in order to produce transgenic plants, including, for example, callus (Type I or Type II), immature embryos, and meristematic tissue.

Another method for physical delivery of DNA to plants is sonication of target cells. Zhang *et al.*, *Bio/Technology* 9: 996 (1991). Alternatively, liposome or spheroplast fusion have been used to introduce expression vectors into plants. Deshayes *et al.*, *EMBO J.*, 4: 2731 (1985), Christou *et al.*, *Proc Natl. Acad. Sci. U.S.A.* 84: 3962 (1987). Direct uptake of DNA into protoplasts using  $\text{CaCl}_2$  precipitation, polyvinyl alcohol or poly-L-ornithine have also been reported. Hain *et al.*, *Mol. Gen. Genet.* 199: 161 (1985) and Draper *et al.*, *Plant Cell Physiol.* 23: 451 (1982). Electroporation of protoplasts and whole cells and tissues have also been described. Donn *et al.*, In Abstracts of VIIth International Congress on Plant Cell and Tissue Culture IAPTC, A2-38, p 53 (1990); D'Halluin *et al.*, *Plant Cell* 4: 1495-1505 (1992) and Spencer *et al.*, *Plant Mol. Biol.* 24: 51-61 (1994).

Following transformation of maize target tissues, expression of the above-described selectable marker genes allows for preferential selection of transformed cells, tissues and/or plants, using regeneration and selection methods now well known in the art. For example, transformed maize immature embryos.

The foregoing methods for transformation would typically be used for producing transgenic inbred lines. Transgenic inbred lines could then be crossed, with another (non-transformed or transformed) inbred line, in order to produce a transgenic hybrid maize plant. Alternatively, a genetic trait which has been engineered into a particular maize line using the foregoing transformation techniques could be moved into another line using traditional backcrossing techniques that are well known in the plant breeding arts. For example, a backcrossing approach could be used to move an engineered trait from a public, non-elite line into an elite line, or from a hybrid maize plant containing a foreign gene in its genome into a line or lines which do not contain that gene. As used

herein, "crossing" can refer to a simple X by Y cross, or the process of backcrossing, depending on the context.

### **Industrial Applicability**

Maize is used as human food, livestock feed, and as raw material in industry. The food uses of maize, in addition to human consumption of maize kernels, include both products of dry- and wet-milling industries. The principal products of maize dry milling are grits, meal and flour. The maize wet-milling industry can provide maize starch, maize syrups, and dextrose for food use. Maize oil is recovered from maize germ, which is a by-product of both dry- and wet-milling industries.

Maize, including both grain and non-grain portions of the plant, is also used extensively as livestock feed, primarily for beef cattle, dairy cattle, hogs, and poultry.

Industrial uses of maize include production of ethanol, maize starch in the wet-milling industry and maize flour in the dry-milling industry. The industrial applications of maize starch and flour are based on functional properties, such as viscosity, film formation, adhesive properties, and ability to suspend particles. The maize starch and flour have application in the paper and textile industries. Other industrial uses include applications in adhesives, building materials, foundry binders, laundry starches, explosives, oil-well muds, and other mining applications.

Plant parts other than the grain of maize are also used in industry: for example, stalks and husks are made into paper and wallboard and cobs are used for fuel and to make charcoal.

The seed of inbred maize line PH51H, the plant produced from the inbred seed, the hybrid maize plant produced from the crossing of the inbred, hybrid seed, and various parts of the hybrid maize plant and transgenic versions of the foregoing, can be utilized for human food, livestock feed, and as a raw material in industry.

### **Performance Examples of PH51H**

In the examples that follow, the traits and characteristics of inbred maize line PH51H are given as a line. The data collected on inbred maize line PH51H is presented for the key characteristics and traits.

### Inbred Comparisons

The results in Table 2A compare inbred PH51H to inbred PHBF0. The results show inbred PH51H flowers significantly earlier (GDU SHD and GDU SLK) than inbred PHBF0. Inbred PH51H shows very high scatter grain resistance and presents a significantly shorter plant with significantly lower ear placement than inbred PHBF0.

The results in Table 2B compare inbred PH51H to inbred PHTD5. The results show inbred PH51H demonstrates above average and significantly higher yield than inbred PHTD5. Inbred PH51H flowers significantly later (GDU SHD and GDU SLK) than inbred PHTD5 and shows above average pollen weight. Inbred PH51H shows significantly higher scatter grain resistance and harder ear texture than inbred PHTD5. Inbred PH51H exhibits significantly better late season plant health than inbred PHTD5.

The results in Table 2C compare inbred PH51H to inbred PH0DH. The results show inbred PH51H demonstrates above average and significantly higher yield than inbred PH0DH and shows high grain test weight. Inbred PH51H sheds pollen significantly earlier (GDU SHD) than inbred PH0DH. Inbred PH51H shows very high scatter grain resistance and significantly higher stay green scores than inbred PH0DH.

The results in Table 2D compare inbred PH51H to inbred PH1MD. The results show inbred PH51H demonstrates above average and significantly higher yield than inbred PH1MD and also shows high test weight of grain. Inbred PH51H sheds pollen significantly earlier (GDU SHD) than inbred PH1MD. Inbred PH51H shows very high scatter grain resistance and better late season plant health than inbred PH1MD.

The results in Table 2E compare inbred PH51H to inbred PH50P. The results show inbred PH51H demonstrates above average yield, though it is significantly lower than inbred PH50P. Inbred PH51H flowers significantly earlier (GDU SHD and GDU SLK) than inbred PH50P and shows well-above average pollen weight. Inbred PH51H shows very high scatter grain resistance and is significantly shorter than inbred PH50P.

### Inbred By Tester Comparisons

The results in Table 3A compare the inbred PH51H and inbred PHTD5, when each inbred is crossed to the same tester lines. The PH51H hybrids demonstrate significantly higher yields than the PHTD5 hybrids. The PH51H hybrids exhibit significantly better stalk lodging resistance and significantly better late season plant health than the PHTD5 hybrids. The PH51H hybrids have a shorter-statured plant type with low ear placement.

The results in Table 3B compare the inbred PH51H and inbred PH50P, when each inbred is crossed to the same tester lines. The PH51H hybrids demonstrate above average yields with below average harvest moisture. The PH51H hybrids have a significantly shorter-statured plant type with significantly lower ear placement than the PH50P hybrids. The PH51H hybrids exhibits significantly better stalk lodging resistance than the PH50P hybrids.

#### Hybrid Comparisons

The results in Table 4A compare inbred PH51H crossed to inbred PH1W2 and inbred PHAA0 crossed to PHTD5. The results show the PH51H/PH1W2 hybrid to demonstrate significantly higher yields than the PHAA0/PHTD5 hybrid. The PH51H/PH1W2 hybrid flowers (GDU SHD and GDU SLK) significantly later than the PHAA0/PHTD5 hybrid. The PH51H/PH1W2 hybrid presents a below average plant height and a below average ear height. The PH51H/PH1W2 hybrid shows above average and significantly better resistance to stalk lodging and significantly higher stay green scores than the PHAA0/PHTD5 hybrid. The PH51H/PH1W2 hybrid develops above average and significantly greater husk cover than the PHAA0/PHTD5 hybrid.

The results in Table 4B compare inbred PH51H crossed to inbred PH1W2 and inbred PHTD5 crossed to PH1W2. The results show the PH51H/PH1W2 hybrid to demonstrate significantly higher yields and significantly better early season growth than the PHTD5/PH1W2 hybrid. The PH51H/PH1W2 hybrid flowers (GDU SHD and GDU SLK) significantly later than the PHTD5/PH1W2 hybrid. The PH51H/PH1W2 hybrid presents a below average plant height and a below average ear height. The PH51H/PH1W2 hybrid shows above average and significantly better resistance to stalk lodging than the PHTD5/PH1W2 hybrid. The PH51H/PH1W2 hybrid shows significantly better late season plant health than the PHTD5/PH1W2 hybrid, which, along with the better stalk lodging resistance, will allow the hybrid to be grown in areas south of the absolute area of adaptation. The PH51H/PH1W2 hybrid develops above average and significantly greater husk cover than the PHTD5/PH1W2 hybrid.

The results in Table 4C compare inbred PH51H crossed to inbred PH1W2 and inbred PHAA0 crossed to PHBF0. The results show the PH51H/PH1W2 hybrid to demonstrate significantly higher yields and significantly higher test weight than the PHAA0/PHBF0 hybrid. The PH51H/PH1W2 hybrid sheds pollen (GDU SHD) significantly later than the PHAA0/PHBF0 hybrid. The PH51H/PH1W2 hybrid shows

above average and significantly better resistance to stalk lodging than the PHAA0/PHBF0 hybrid. The PH51H/PH1W2 hybrid has significantly better stay green scores than the PHAA0/PHBF0 hybrid.

5 The results in Table 4D compare inbred PH51H crossed to inbred PH1W2 and inbred PH1MD crossed to PH0AV. The results show the PH51H/PH1W2 hybrid to demonstrate significantly higher yields, significantly higher test weight and significantly better early season growth than the PH1MD/PH0AV hybrid. The PH51H/PH1W2 hybrid flowers (GDU SHD and GDU SLK) significantly later than the PH1MD/PH0AV hybrid. The PH51H/PH1W2 hybrid has a shorter plant stature than average and a significantly  
10 lower ear placement than the PH1MD/PH0AV hybrid. The PH51H/PH1W2 hybrid shows above average and significantly better resistance to stalk lodging and significantly better late season plant health than the PH1MD/PH0AV hybrid. The PH51H/PH1W2 hybrid develops above average and significantly greater husk cover than the PH1MD/PH0AV hybrid.

15 The results in Table 4E compare inbred PH51H crossed to inbred PH1W2 and inbred PH50P crossed to PH1W2. The results show the PH51H/PH1W2 hybrid to demonstrate above average yields and significantly better early season growth than the PH50P/PH1W2 hybrid. The PH51H/PH1W2 hybrid presents a below average and significantly shorter plant height than the PH50P/PH1W2 hybrid. The PH51H/PH1W2  
20 hybrid shows above average and significantly better resistance to stalk lodging than the PH50P/PH1W2 hybrid. The PH51H/PH1W2 hybrid has exceptionally high late season plant health scores. The PH51H/PH1W2 hybrid develops above average and significantly greater husk cover than the PH50P/PH1W2 hybrid.

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TABLE 2A  
PAIRED INBRED COMPARISON REPORT

VARIETY #1 = PH51H  
VARIETY #2 = PHBFO

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		EGR	EST	TIL	GDU	GDU	POL	POL	POL	TAS
		WTH	CNT	LER	SHD	SLK	WT	WT	SC	SZ
		ABS	ABS	ABS	ABS	ABS	ABS	%MN	ABS	ABS
TOTAL SUM	1	5.4	29.4	0.8	122.0	123.5	115.6	81	3.0	5.4
	2	5.1	28.6	2.8	123.8	127.4	230.3	163	6.0	5.3
	LOCS	11	18	15	40	40	2	2	1	28
	REPS	11	18	15	40	40	2	2	1	28
	DIFF	0.3	0.8	2.0	1.8	3.9	114.8	82	3.0	0.1
	PR > T	.518	202	.047+	.014+	.000#	.251	.276		.774
		PLT	EAR	RT	STA	STK	BRT	SCT	EAR	TEX
		HT	HT	LDG	GRN	LDG	STK	GRN	SZ	EAR
		ABS	ABS	ABS	ABS	ABS	ABS	ABS	ABS	ABS
TOTAL SUM	1	75.2	31.6	90.7	5.0	100.0	100.0	8.0	8.0	7.0
	2	79.0	35.2	76.5	5.0	100.0	97.1	8.0	5.0	1.5
	LOCS	12	11	3	4	1	2	2	1	2
	REPS	12	11	3	4	1	2	2	1	2
	DIFF	3.8	3.6	14.3	0.0	0.0	2.9	0.0	3.0	5.5
	PR > T	.001#	.030+	.423	.999		.500	.999		.058*
		EAR	BAR	NLF	GOS	STW	HD	FUS	GIB	
		MLD	PLT	BLT	WLT	WLT	SMT	ERS	ERS	
		ABS	ABS	ABS	ABS	ABS	ABS	ABS	ABS	
TOTAL SUM	1	8.0	97.5	8.0	8.5	7.0	100.0	1.0	3.5	
	2	5.0	97.9	6.0	6.5	6.0	89.2	3.5	6.0	
	LOCS	1	9	1	1	1	2	2	1	
	REPS	1	9	1	2	1	4	2	2	
	DIFF	3.0	0.4	2.0	2.0	1.0	10.8	2.5	2.5	
	PR > T		822				.325	.500		

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

TABLE 2B  
PAIRED INBRED COMPARISON REPORT

VARIETY #1 = PH51H  
VARIETY #2 = PHTD5

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		BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	EGR WTH ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS	GDU SLK ABS
TOTAL SUM	1	90.2	115	20.8	58.8	5.6	31.4	2.5	122.0	123.3
	2	74.1	95	18.6	57.5	5.2	32.9	1.4	119.6	121.0
	LOCS	24	24	27	5	24	38	21	59	58
	REPS	24	24	27	5	24	45	21	59	58
	DIFF	16.2	20	2.2	1.2	0.5	1.5	1.1	2.4	2.4
	PR > T	.000#	.000#	.005#	.400	.071*	.242	.372	.000#	.000#

		POL WT ABS	POL WT %MN	POL SC ABS	TAS BLS ABS	TAS SZ ABS	PLT HT ABS	EAR HT ABS	RT LDG ABS	STA GRN ABS
TOTAL SUM	1	177.0	105	3.0	7.0	5.6	71.8	28.5	91.0	5.3
	2	176.2	112	5.0	7.0	5.6	69.5	32.1	92.6	4.1
	LOCS	4	4	1	1	38	29	22	6	15
	REPS	4	4	1	1	38	30	23	6	15
	DIFF	0.9	7	2.0	0.0	0.0	2.3	3.7	1.6	1.2
	PR > T	.986	.798			.999	.009#	.055*	.791	.016+

		STK LDG ABS	BRT STK ABS	SCT GRN ABS	EAR SZ ABS	TEX EAR ABS	EAR MLD ABS	BAR PLT ABS	NLF BLT ABS	GOS WLT ABS
TOTAL SUM	1	99.2	99.6	8.2	8.0	7.0	6.2	98.4	8.0	8.5
	2	97.3	100.0	6.0	5.0	4.0	6.8	99.3	6.0	5.0
	LOCS	5	5	5	1	2	5	16	1	1
	REPS	5	5	5	1	2	5	16	1	2
	DIFF	1.9	0.4	2.2	3.0	3.0	0.6	0.9	2.0	3.5
	PR > T	.374	.374	.004#		.000#	.426	.097*		

		STW WLT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	CLD TST ABS	CLD TST %MN	KSZ DCD ABS
TOTAL SUM	1	7.0	100.0	1.0	3.5	82.9	100	1.3
	2	6.0	64.5	4.0	4.0	81.0	97	2.0
	LOCS	1	2	2	1	9	9	9
	REPS	1	4	2	2	9	9	9
	DIFF	1.0	35.5	3.0	0.5	1.9	3	0.7
	PR > T		.166	.374		.557	.503	.169

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

TABLE 2C  
PAIRED INBRED COMPARISON REPORT

VARIETY #1 = PH51H  
VARIETY #2 = PH0DH

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		BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	EGR WTH ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS	GDU SLK ABS
TOTAL SUM	1	91.7	119	22.1	58.3	5.5	30.0	2.2	123.2	124.8
	2	83.3	108	20.4	60.3	5.8	28.7	1.9	124.2	126.0
	LOCS	12	12	14	1	18	30	13	48	47
	REPS	12	12	14	1	18	37	13	48	47
	DIFF	8.4	11	1.6	2.0	0.3	1.3	0.3	1.0	1.1
	PR > T	.007#	.009#	.026+		.462	.209	.867	.040+	.057*

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		POL WT ABS	POL WT %MN	POL SC ABS	TAS BLS ABS	TAS SZ ABS	PLT HT ABS	EAR HT ABS	RT LDG ABS	STA GRN ABS
TOTAL SUM	1	125.9	97	3.0	7.0	5.7	72.7	29.1	90.7	5.0
	2	123.7	87	5.0	6.0	4.5	70.4	26.4	96.3	3.8
	LOCS	3	3	1	1	31	27	20	3	12
	REPS	3	3	1	1	31	28	21	3	12
	DIFF	2.2	11	2.0	1.0	1.2	2.3	2.7	5.6	1.2
	PR > T	.979	.865			.000#	.015+	.024+	.423	.046+

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		STK LDG ABS	BRT STK ABS	SCT GRN ABS	EAR SZ ABS	TEX EAR ABS	EAR MLD ABS	BAR PLT ABS	NLF BLT ABS	GOS WLT ABS
TOTAL SUM	1	98.1	99.5	8.2	8.0	7.0	6.2	98.3	6.3	7.0
	2	91.7	96.2	7.8	5.0	5.0	7.8	97.6	7.0	8.0
	LOCS	2	4	5	1	2	5	15	3	2
	REPS	2	4	5	1	2	5	15	5	4
	DIFF	6.4	3.3	0.4	3.0	2.0	1.6	0.7	0.7	1.0
	PR > T	.500	.299	.587		.500	.099*	.624	.423	.500

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		STW WLT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS	CLD TST ABS	CLD TST %MN	KSZ DCD ABS
TOTAL SUM	1	7.0	99.0	1.0	4.2	6.0	77.5	101	1.5
	2	6.0	99.3	6.0	3.3	6.5	82.0	107	4.3
	LOCS	1	4	2	3	1	4	4	4
	REPS	1	8	2	6	2	4	4	4
	DIFF	1.0	0.3	5.0	0.8	0.5	4.5	6	2.8
	PR > T		.391	.344	.300		.131	.119	.195

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG



TABLE 2D  
PAIRED INBRED COMPARISON REPORT

VARIETY #1 = PH51H

VARIETY #2 = PH1MD

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		BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	EGR WTH ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS	GDU SLK ABS
TOTAL SUM	1	92.5	117	19.8	57.8	5.7	33.3	1.0	122.1	123.6
	2	86.7	109	19.1	57.0	5.0	32.1	1.4	123.1	124.0
	LOCS	40	40	45	13	26	45	29	61	60
	REPS	40	40	45	13	26	59	29	61	62
	DIFF	5.8	7	0.7	0.8	0.7	1.2	0.4	1.0	0.4
	PR > T	.037+	.041+	.109	.459	.038+	.038+	.615	.029+	.502

		POL SC ABS	TAS BLS ABS	TAS SZ ABS	PLT HT ABS	EAR HT ABS	RT LDG ABS	STA GRN ABS	STK LDG ABS	BRT STK ABS
TOTAL SUM	1	3.0	7.0	5.6	71.5	28.3	82.6	5.5	99.1	96.6
	2	5.0	6.0	4.2	61.9	27.2	84.5	4.6	98.4	99.5
	LOCS	1	1	37	32	25	12	17	10	10
	REPS	1	1	37	33	26	12	17	10	10
	DIFF	2.0	1.0	1.5	9.6	1.1	1.8	0.9	0.7	2.9
	PR > T			.000#	.000#	.229	.489	.060*	.554	.275

		SCT GRN ABS	EAR SZ ABS	TEX EAR ABS	EAR MLD ABS	BAR PLT ABS	DRP EAR ABS	NLF BLT ABS	GOS WLT ABS	STW WLT ABS
TOTAL SUM	1	8.3	8.0	6.3	6.7	97.3	100.0	6.3	7.0	6.0
	2	8.3	4.5	4.0	7.3	96.2	100.0	6.0	7.3	5.3
	LOCS	7	2	4	7	25	2	3	2	2
	REPS	7	2	4	7	25	2	5	4	4
	DIFF	0.0	3.5	2.3	0.6	1.1	0.0	0.3	0.3	0.7
	PR > T	.999	.395	.058*	.386	.392	.999	.423	.910	.295

		HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS	CLD TST ABS	CLD TST %MN	KSZ DCD ABS
TOTAL SUM	1	99.0	1.0	4.2	6.0	81.5	98	1.3
	2	94.2	8.5	3.0	4.5	84.6	102	5.7
	LOCS	4	2	3	1	17	17	17
	REPS	8	2	6	2	17	17	17
	DIFF	4.8	7.5	1.2	1.5	3.1	4	4.4
	PR > T	.110	.042+	.317		.081*	.079*	.000#

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

TABLE 2E  
PAIRED INBRED COMPARISON REPORT

VARIETY #1 = PH51H

VARIETY #2 = PH50P

		BU ACR ABS	BU ACR %MN	MST ABS	TST WT ABS	EGR WTH ABS	EST CNT ABS	TIL LER ABS	GDU SHD ABS	GDU SLK ABS
TOTAL SUM	1	89.7	114	20.2	57.5	5 6	33.3	1.1	121.5	122.8
	2	97.2	123	20.4	57.8	5 8	33.5	1.2	123.7	126.0
	LOCS	36	36	39	9	32	47	27	70	70
	REPS	36	36	39	9	32	61	27	70	72
	DIFF	7.4	9	0.1	0.3	0 3	0.2	0.1	2.2	3.3
	PR > T	.008#	.013+	771	.757	.222	.770	.884	.000#	.000#

		POL WT ABS	POL WT %MN	POL SC ABS	TAS BLS ABS	TAS SZ ABS	PLT HT ABS	EAR HT ABS	RT LDG ABS	STA GRN ABS
TOTAL SUM	1	238.5	129	3.0	7.0	5.5	71.5	28.5	81.4	5.1
	2	153.3	70	4.0	6.0	5.0	80.0	29.1	82.1	5.0
	LOCS	2	2	1	1	45	38	27	11	18
	REPS	2	2	1	1	45	40	29	11	18
	DIFF	85.2	59	1.0	1.0	0.6	8.6	0.6	0.7	0.1
	PR > T	.158	.335			.005#	.000#	.550	.916	911

		STK LDG ABS	BRT STK ABS	SCT GRN ABS	EAR SZ ABS	TEX EAR ABS	EAR MLD ABS	BAR PLT ABS	DRP EAR ABS	NLF BLT ABS
TOTAL SUM	1	99.0	96.6	7.9	8.0	6.3	6.0	97.4	100.0	6.3
	2	98.9	94.4	7.1	8.5	5.3	6.2	97.9	100.0	5.3
	LOCS	7	10	8	2	4	9	23	1	3
	REPS	7	10	8	2	4	9	23	1	5
	DIFF	0.1	2.2	0.8	0.5	1.0	0.2	0.5	0.0	1.0
	PR > T	.819	.451	.244	.500	.391	.777	.526		.000#

		GOS WLT ABS	STW WLT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS	CLD TST ABS	CLD TST %MN	KSZ DCD ABS
TOTAL SUM	1	7.0	6.0	99.0	1.0	4.2	6.0	82.5	98	1.2
	2	6.5	5.5	90.0	2.5	5.0	5.5	88.6	105	2.3
	LOCS	2	2	4	2	3	1	13	13	13
	REPS	4	4	8	2	5	2	13	13	13
	DIFF	0.5	0.5	9.0	1.5	0.8	0.5	6.1	8	1.1
	PR > T	.795	.500	.097*	.205	.464		.021+	.022+	.009#

\* = 10% SIG

+ = 5% SIG

# = 1% SIG

TABLE 3A

Average Inbred By Tester Performance Comparing PH51H To PHTD5 Crossed  
To The Same Inbred Testers And Grown In The Same Experiments.

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		BU ACR ABS	BU ACR %MN	MST %MN	EGR WTH %MN	EST CNT %MN	GDU SHD %MN	GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN
TOTAL SUM	REPS	200	200	200	75	12	65	56	289	86	83
	LOCS	131	131	131	45	7	43	35	189	56	54
	PH51H	186	106	101	103	106	102	101	100	99	97
	PHTD5	178	102	94	96	99	99	98	101	97	93
	DIFF	8	4	7	7	7	3	3	0	2	4
	PR > T	0.00	0.00	0.00	0.02	0.18	0.00	0.00	0.99	0.00	0.00

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		RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	STW WLT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS	ECB 1LF ABS
TOTAL SUM	REPS	37	88	107	27	4	2	10	8	2	8
	LOCS	34	56	70	23	2	1	5	4	1	4
	PH51H	104	124	104	101	9	98	6	5	6	5
	PHTD5	112	101	101	101	8	98	6	6	5	5
	DIFF	8	22	2	0	1	0	0	1	1	0
	PR > T	0.05	0.00	0.02	0.99	0.50	0.99	0.99	0.60		0.99

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		ECB 2SC ABS	DRP EAR %MN	GLF SPT ABS	NLF BLT ABS
TOTAL SUM	REPS	10	13	3	8
	LOCS	5	10	2	6
	PH51H	8	100	6	7
	PHTD5	8	100	5	7
	DIFF	1	0	1	1
	PR > T	0.41	0.99	0.50	0.25

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\*PR > T values are valid only for comparisons with Locs >= 10.

TABLE 3B

Average Inbred By Tester Performance Comparing PH51H To PH50P Crossed  
To The Same Inbred Testers And Grown In The Same Experiments.

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		PRM ABS	BU ACR ABS	BU ACR %MN	PRM SHD ABS	MST %MN	EGR WTH %MN	EST CNT %MN	GDU SHD %MN	GDU SLK %MN	STK CNT %MN
TOTAL SUM	REPS	31	1356	1356	29	1446	540	41	130	107	1916
	LOCS	31	932	932	29	1009	340	32	86	65	1321
	PH51H	95	178	101	99	98	102	102	101	101	100
	PH50P	95	181	102	100	97	104	102	102	101	100
	DIFF	0	3	1	1	0	1	0	1	0	0
	PR > T	0.99	0.00	0.00	0.00	0.99	0.23	0.99	0.03	0.99	0.99
		PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	STW WLT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS
TOTAL SUM	REPS	521	518	259	623	715	222	4	2	10	8
	LOCS	357	356	251	449	531	189	2	1	5	4
	PH51H	99	98	100	99	102	100	9	98	6	5
	PH50P	104	101	98	101	98	100	9	100	7	6
	DIFF	5	2	2	2	3	1	0	2	1	0
	PR > T	0.00	0.00	0.29	0.31	0.00	0.23	0.99		0.19	0.99
		EYE SPT ABS	ECB 1LF ABS	ECB 2SC ABS	DRP EAR %MN	GLF SPT ABS	NLF BLT ABS				
TOTAL SUM	REPS	2	12	18	96	9	12				
	LOCS	1	6	9	86	5	8				
	PH51H	6	5	8	100	4	7				
	PH50P	5	5	7	100	5	7				
	DIFF	2	0	1	0	1	0				
	PR > T		0.99	0.06	0.99	0.33	0.99				

\*PR > T values are valid only for comparisons with Locs >= 10.

TABLE 4A  
INBREDS IN HYBRID COMBINATION REPORT

VARIETY #1 = PH51H/PH1W2  
VARIETY #2 = PHAA0/PHTD5

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		PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR %MN	MST %MN	TST WT ABS	EGR WTH %MN	EST CNT %MN	GDU SHD %MN
TOTAL SUM	1	96	100	185.9	106	100	56.0	104	102	102
	2	91	91	160.2	92	89	56.8	106	102	95
	LOCS	4	3	155	155	156	66	65	20	54
	REPS	4	3	159	159	159	69	65	20	62
	DIFF	4	8	25.7	15	11	0.8	3	0	7
	PR > T	.000#	.001#	.000#	.000#	.000#	.000#	.347	.999	.000#

		GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	DRP EAR %MN
TOTAL SUM	1	101	101	99	97	103	120	104	101	100
	2	95	100	94	97	101	73	97	101	100
	LOCS	41	219	66	65	40	72	89	28	17
	REPS	45	273	71	69	41	74	89	28	17
	DIFF	6	0	5	0	3	47	6	0	0
	PR > T	.000#	.399	.000#	.999	.451	.000#	.000#	.999	.999

		GLF SPT ABS	NLF BLT ABS	GOS WLT ABS	STW WLT ABS	ANT ROT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS
TOTAL SUM	1	5.5	7.3	7.3	7.8	4.5	99.2	5.8	4.8	6.0
	2	3.8	4.8	7.0	6.0	4.0	82.1	6.8	6.3	4.5
	LOCS	2	6	2	4	2	3	9	6	4
	REPS	3	9	4	4	4	6	9	9	6
	DIFF	1.8	2.4	0.3	1.8	0.5	17.1	1.0	1.4	1.5
	PR > T	.258	.022+	.795	.133	.795	.274	.028+	.034+	.014+

		ECB 1LF ABS	ECB 2SC ABS	HSK CVR ABS	HSK CVR %MN	OIL T ABS	PRO T ABS	STR T ABS
TOTAL SUM	1	4.5	7.4	6.3	127	4.3	10.3	71.0
	2	4.0	7.4	4.9	98	4.8	8.8	69.6
	LOCS	2	8	34	34	2	2	2
	REPS	2	8	34	34	2	2	2
	DIFF	0.5	0.0	1.4	28	0.5	1.5	1.3
	PR > T	.500	.999	.000#	.000#	.119	.414	.370

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

TABLE 4B  
INBREDS IN HYBRID COMBINATION REPORT

VARIETY #1 = PH51H/PH1W2

VARIETY #2 = PHTD5/PH1W2

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		PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR %MN	MST %MN	TST WT ABS	EGR WTH %MN	EST CNT %MN	GDU SHD %MN
TOTAL SUM	1	96	100	186.8	106	101	56.4	102	106	102
	2	94	96	178.8	102	94	56.8	96	99	99
	LOCS	2	2	138	138	139	56	55	7	50
	REPS	2	2	140	140	141	58	55	7	59
	DIFF	3	4	8 0	4	7	0 4	6	7	3
	PR > T	.131	.095*	.000#	.000#	.000#	158	.018+	.184	.000#

		GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	DRP EAR %MN
TOTAL SUM	1	101	100	99	97	104	122	104	101	100
	2	99	101	97	93	112	101	101	101	100
	LOCS	40	203	62	60	36	62	78	23	10
	REPS	45	264	68	65	37	64	78	23	10
	DIFF	3	0	2	4	8	22	3	0	0
	PR > T	.000#	.999	.002#	.001#	.051*	.000#	.005#	.999	.999

		GLF SPT ABS	NLF BLT ABS	GOS WLT ABS	STW WLT ABS	ANT ROT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS
TOTAL SUM	1	5.5	7.3	7.3	7.8	4.5	99.2	5.8	4.8	6.0
	2	4.5	6.5	7.0	7.5	2.0	96.2	5.8	5.5	5.6
	LOCS	2	6	2	4	2	3	9	6	4
	REPS	3	9	4	4	4	6	9	9	6
	DIFF	1.0	0.8	0.3	0.3	2.5	3.0	0.0	0.7	0.4
	PR > T	.500	.248	.500	.638	.126	.423	.999	.371	.486

		ECB 1LF ABS	ECB 2SC ABS	HSK CVR ABS	HSK CVR %MN	OIL T ABS	PRO T ABS	STR T ABS
TOTAL SUM	1	5.1	7.4	6 4	131	4.3	10 3	71.0
	2	4.9	6.7	5 2	106	4.4	9 0	70.2
	LOCS	4	9	28	28	2	2	2
	REPS	6	10	28	28	2	2	2
	DIFF	0.3	0.7	1 2	26	0.2	1 3	0.8
	PR > T	.391	.122	.001#	.001#	.674	.311	.610

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

TABLE 4C  
INBREDS IN HYBRID COMBINATION REPORT

VARIETY #1 = PH51H/PH1W2  
VARIETY #2 = PHAA0/PHBFO

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		PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR %MN	MST %MN	TST WT ABS	EGR WTH %MN	EST CNT %MN	GDU SHD %MN
TOTAL SUM	1	95	99	176.9	107	95	53.7	109	99	100
	2	93	91	156.3	95	90	52.3	105	96	97
	LOCS	2	1	20	20	20	10	8	12	6
	REPS	2	1	22	22	21	11	8	12	6
	DIFF	3	7	20.5	12	5	1.4	4	4	4
	PR > T	.006#		.000#	.000#	.007#	.001#	.642	.395	.016+

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		GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	DRP EAR %MN
TOTAL SUM	1	100	101	101	98	102	109	101	101	100
	2	96	96	100	104	102	61	96	103	100
	LOCS	2	26	6	6	5	12	13	5	7
	REPS	2	27	7	7	5	12	13	5	7
	DIFF	4	6	1	6	0	48	6	2	0
	PR > T	.430	.012+	.175	.118	.999	.002#	.028+	.236	.999

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		HSK CVR ABS	HSK CVR %MN
TOTAL SUM	1	6.2	105
	2	5.8	100
	LOCS	6	6
	REPS	6	6
	DIFF	0.3	5
	PR > T	.530	.563

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

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TABLE 4D  
INBREDS IN HYBRID COMBINATION REPORT

VARIETY #1 = PH51H/PH1W2  
VARIETY #2 = PH1MD/PH0AV

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		PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR %MN	MST %MN	TST WT ABS	EGR WTH %MN	EST CNT %MN	GDU SHD %MN
TOTAL SUM	1	96	99	187.2	105	101	56.7	102	108	102
	2	93	96	169.2	95	93	55.7	92	103	99
	LOCS	1	1	73	73	74	31	39	5	27
	REPS	1	1	75	75	76	33	39	5	32
	DIFF	3	3	18.0	10	8	1.0	10	5	3
	PR > T			.000#	.000#	.000#	.002#	.011+	.075*	.000#

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		GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	DRP EAR %MN
TOTAL SUM	1	101	101	98	96	100	107	104	102	100
	2	98	100	95	102	103	75	99	101	100
	LOCS	26	113	36	35	4	39	44	4	3
	REPS	31	154	41	39	4	41	44	4	3
	DIFF	3	1	3	6	4	32	5	1	0
	PR > T	.000#	.201	.001#	.001#	.391	.000#	.015+	.507	.999

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		GLF SPT ABS	NLF BLT ABS	STW WLT ABS	ANT ROT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS	ECB 1LF ABS
TOTAL SUM	1	5.0	6.0	8.5	4.5	97.6	5.8	5.3	6.0	4.5
	2	6.0	5.5	6.0	1.5	97.6	6.0	5.4	4.0	4.5
	LOCS	1	2	2	1	1	9	4	1	2
	REPS	1	3	2	2	2	9	5	2	2
	DIFF	1.0	0.5	2.5	3.0	0.1	0.2	0.1	2.0	0.0
	PR > T		.500	.344			.622	.873		.999

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		ECB 2SC ABS	HSK CVR ABS	HSK CVR %MN
TOTAL SUM	1	7.4	6.5	139
	2	7.3	5.6	118
	LOCS	8	19	19
	REPS	8	19	19
	DIFF	0.1	0.9	22
	PR > T	.732	.007#	.010+

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG



TABLE 4E  
INBREDS IN HYBRID COMBINATION REPORT

VARIETY #1 = PH51H/PH1W2  
VARIETY #2 = PH50P/PH1W2

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		PRM ABS	PRM SHD ABS	BU ACR ABS	BU ACR %MN	MST %MN	TST WT ABS	EGR WTH %MN	EST CNT %MN	GDU SHD %MN
TOTAL SUM	1	96	100	187.9	106	100	56 0	103	102	102
	2	95	100	189.3	107	99	55 9	97	102	102
	LOCS	4	3	171	171	172	65	76	19	54
	REPS	4	3	175	175	175	68	76	19	61
	DIFF	0	1	1.4	1	1	0 2	6	1	0
	PR > T	.999	.254	.314	.284	.014+	535	.024+	.712	.999
		GDU SLK %MN	STK CNT %MN	PLT HT %MN	EAR HT %MN	RT LDG %MN	STA GRN %MN	STK LDG %MN	BRT STK %MN	DRP EAR %MN
TOTAL SUM	1	101	101	99	98	103	120	103	101	100
	2	101	101	103	99	110	114	99	101	100
	LOCS	42	233	78	77	40	75	102	28	17
	REPS	47	288	84	82	40	77	102	28	17
	DIFF	0	0	4	1	7	6	4	0	0
	PR > T	.999	.999	.000#	.564	.266	.287	.001#	.999	.999
		GLF SPT ABS	NLF BLT ABS	GOS WLT ABS	STW WLT ABS	ANT ROT ABS	HD SMT ABS	FUS ERS ABS	GIB ERS ABS	EYE SPT ABS
TOTAL SUM	1	5.5	6.9	7.3	7.8	4.5	99.2	5.8	4.4	6.0
	2	5.3	6.8	7.3	7.0	4.0	98.0	6.9	5.4	4.6
	LOCS	2	7	2	4	2	3	9	7	4
	REPS	3	10	4	4	4	6	9	10	6
	DIFF	0.3	0.1	0.0	0.8	0.5	1.2	1.1	1.0	1.4
	PR > T	.500	.689	.999	.391	.705	.681	.051*	.162	.010+
		ECB 1LF ABS	ECB 2SC ABS	HSK CVR ABS	HSK CVR %MN	OIL T ABS	PRO T ABS	STR T ABS		
TOTAL SUM	1	5.1	7.4	6.3	127	4.3	10 3	71.0		
	2	5.5	6.8	5.4	107	5.1	9 9	69.2		
	LOCS	4	9	34	34	2	2	2		
	REPS	6	10	34	34	2	2	2		
	DIFF	0.4	0.6	0.9	19	0.9	0 4	1.8		
	PR > T	.624	.171	.000#	.001#	.500	.423	.300		

\* = 10% SIG  
+ = 5% SIG  
# = 1% SIG

### Deposits

264317  
5 A deposit of the seed of inbred PH51H is and has been maintained by Pioneer Hi-Bred International, Inc., 800 Capital Square, 400 Locust Street, Des Moines, Iowa 50309-2340, since prior to the filing date of this application. Access to this deposit will be available during the pendency of the application to the Commissioner of Patents and Trademarks and person determined by the Commissioner to be entitled thereto upon request. Upon allowance of any claims in the application, the Applicant(s) will make available to the public without restriction a deposit of at least 2500 seeds of inbred PH51H with the American Type Culture Collection (ATCC), Manassas, Virginia, 20110.  
10 The seeds deposited with the ATCC will be taken from the same deposit maintained at Pioneer Hi-Bred and described above. Additionally, Applicant(s) will meet all the requirements of 37 C.F.R. §1.801 - 1.809, including providing an indication of the viability of the sample when the deposit is made. This deposit of Inbred Maize Line PH51H will be maintained in the ATCC Depository, which is a public depository, for a  
15 period of 30 years, or 5 years after the most recent request, or for the enforceable life of the patent, whichever is longer, and will be replaced if it ever becomes nonviable during that period. Applicant will impose no restrictions on the availability of the deposited material from the ATCC; however, Applicant has no authority to waive any restrictions imposed by law on the transfer of biological material or its transportation in commerce.  
20 Applicant does not waive any infringement of its rights granted under this patent or under the Plant Variety Protection Act (7 USC 2321 et seq.).

The foregoing invention has been described in detail by way of illustration and example for purposes of clarity and understanding. However, it will be obvious that  
25 certain changes and modifications such as single gene conversions and mutations, somoclonal variants, variant individuals selected from large populations of the plants of the instant inbred and the like may be practiced within the scope of the invention, as limited only by the scope of the appended claims.